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COMPARISON STUDY OF JANUS AND JLINK

by

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The experiment simulated three scenarios: armored, armored coalition, and light infantry battalions attacking against a defending company. All scenarios were executed in two contrasting environments. The simulation included the recently developed JLink features Family of Scatterable Mine (FASCAM) and chemical artillery.

The thesis used five Measures of Performance to base the assessment: 1) FASCAM kills, 2) Chemical Artillery Kills, 3) Detection Ranges, 4) Kill Ranges, and 5) Loss Exchange Ratio. The statistical tests used for analysis were the Analysis of Variance (ANOVA) test, two-sample *t*-test, and Wilcoxon test.

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COMPARISON STUDY OF JANUS AND JLINK

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EXECUTIVE SUMMARY

The Army relies heavily on computer simulation as a training an analytical tool. One simulation the Army uses is Janus, a high resolution combat simulation model design to operate in a stand-alone mode. There is an ongoing research effort to link Janus with other constructive simulations or virtual simulators. The present standard for linking different models is Distributed Interactive Simulation (DIS). Janus can operate in a DIS environment using a cell adapter unit called the World Modeler. The combination of Janus and the World Modeler is known as JLink. A goal of JLink is to replicate the training and analytic fidelity of stand-alone Janus in a distributed (JLink) exercise. The level of fidelity may be gauged by comparing the results of a scenario run in stand-alone Janus with the results from the same scenario run in JLink. The purpose of this thesis is to assess the current state of JLink development by measuring the amount of distortion between stand-alone Janus and JLink.

The experiment tested specific areas of JLink which had yet been assessed. Previously, only rudimentary scenarios had been tested in a single environment. This thesis tested scenarios using different types of combat units in two different environments. The thesis also tested JLink's ability to portray coalition warfare. Finally, the thesis assessed recent software inputs to JLink which simulated specific combat functions, in particular Family of Scatterable Mines (FASCAM) and chemical artillery.

The experimental design used to assess these aspects of JLink included armored and light infantry units. The first scenario involved a Soviet-equipped armored battalion attacking against a defending US-equipped armored company. The second scenario was identical to the first except that the attacking battalion was divided into two separate forces, both attacking the armored company. This scenario was used to assess JLink's ability to replicate a coalition battle. The last scenario involved a Soviet-equipped light battalion attacking against a US-equipped light infantry company. All three scenarios were executed in two different environments. The two environments selected were Fort Hunter Liggett, California (HL) and Southwest Asia (SWA). These two environments offered contrasting terrain, the first being wooded with rolling hills and the second being flat and open. Using different types of units in contrasting terrain permitted assessment of JLink's ability to portray varied scenarios. To test the specific combat functions of FASCAM and chemical kills, the defending company used these weapons in every scenario.

The Measures of Performance (MOPs) selected for analysis were FASCAM kills, chemical kills, detection range, kill range, rounds fired, and Loss Exchange Ratio (LER). These MOPs allowed for analysis of the basic procedures of an engagement. First, one entity must detect another entity. Once detected, the entity may elect to shoot at the target. Analyzing detection range, kill range, and rounds fired offers a quantitative method of assessing these basic engagement procedures. The LER is a function of the

other MOPs and measures the overall outcome of the battle. The MOPs FASCAM kills and chemical kills were used to assess JLink's ability to simulate those functions.

The statistical tests used to analyze the data were the Analysis of Variance (ANOVA), two sample *t*-test, and the nonparametric Wilcoxon test. First the data was analyzed using the ANOVA test whether overall averages for a specific MOP were statistically similar between the Janus and JLink runs taking into account all scenarios and environments. The ANOVA was also used to determine interactions between the scenarios, environments, and the mode (Janus or JLink) for each MOP. In the case where the ANOVA determined that the Janus and JLink means were statistically different, pair-wise two sample *t*-tests were used to identify where the differences in the means existed. Finally, the nonparametric Wilcoxon was also used in a pair-wise method to test those populations which did not satisfy *t*-test assumptions and to substantiate the *t*-test results.

The results of the analysis show that JLink requires adjustments to artillery delivery methods in order to calibrate chemical artillery discrepancies and detection range issues. JLink chemical artillery killed far fewer entities than Janus, and JLink consistently detected farther than Janus. The finding is that to match Janus, JLink must simulate an artillery volley as one large cloud, like Janus, as opposed to individual rounds, as dictated by DIS standards. In general, JLink accurately portrays coalition warfare and satisfactorily replicates armored and infantry scenarios in contrasting environments.

I. INTRODUCTION

The Army relies heavily on computer simulations for training and force analysis. One simulation in use today is Janus, an event-driven wargame named for the two-faced Roman god Janus, who was the guardian of the portals of Rome and the patron of beginnings and endings. For nearly three decades, Janus has proven to be a valuable training and analysis tool and has evolved into a legacy model with many validated features. The current task is to link Janus, which is designed to operate in a stand-alone mode, with other live, virtual, or constructive models.

The present standard used to connect two or more models is known as Distributed Interactive Simulation (DIS). Janus is capable of operating in a DIS environment using a cell adapter unit called the World Modeler. The World Modeler is software, designed to run on a low-end Silicon Graphics computer, which performs functions required by the DIS architecture that are not performed by Janus. The combination of Janus and the World Modeler is known as JLink [Ref. 1:p.1].

JLink combines the training and analytic potential of a widely fielded constructive simulation, Janus, with a DIS-compatible simulation. A goal of the JLink system is to replicate the analytical and training fidelity of a stand-alone Janus in a distributed (JLink) exercise. This level of fidelity may be gauged by comparing the results of a scenario run in stand-alone Janus with the results of the same scenario run in JLink, using similar starting conditions. The purpose of this thesis is to assess the current state of JLink development by measuring the amount of distortion between stand-alone Janus and distributed Janus using JLink, by applying statistical analysis. The assessment will aid in

identifying credible areas of JLink as well as aspects of JLink which require further development. As interest in JLink continues to grow throughout the Army and across services, improvements in JLink fidelity will prove valuable and return many training and analytical benefits.

A. JANUS

1. Janus Background

Lawrence Livermore National Laboratory originally developed Janus in the 1970s, with the current version developed by Training and Doctrine Command Analysis Center (TRAC) at White Sands Missile Range, New Mexico. Janus is a stochastic, interactive, high resolution, multisided, model with a robust database and a detailed post-processor for gathering results.

Being a stochastic model, Janus uses a random number generator and probabilities to determine the outcome of detections and engagements. Janus random number seeds range from 1 to 99. Prior to executing a scenario, the user may set the random number seed manually or elect to have Janus randomly select the seed. Since Janus is an event based model, the user can achieve exact replication if the same random number seed is selected and there is no human interaction.

The interactive nature of Janus permits its users to make decisions during the scenario to influence the outcome of the battle. Due to the variability of user inputs between scenarios, interaction will produce different results for two Janus scenarios using an identical random number seed. Examples of interactive functions include creating or

altering movement routes, planning and firing artillery missions, and mounting/dismounting units. User interaction is not necessary for pre-planned scenarios designed to fight two opposing forces. For purposes of this thesis, all scenarios were pre-planned and included no interaction.

Janus is a high resolution model because it represents entities down to individual systems. However, when practical the user may aggregate entities, with artillery systems typically being aggregated up to 40 entities [Ref. 2:p.21]. The situation and scenario will generally dictate the level of aggregation, with Janus users often aggregating to the lowest useful level in order to take advantage of Janus' high-resolution capabilities.

Janus can also model up to six different sides for a given scenario, to include simulating fratricide. Janus offers the option to separate the sides among different workstations (primarily for training) or play all sides on one workstation (primarily for analysis).

Janus possesses a robust database which permits the user to define a weapon system extensively or capture the detailed factors required for the scenario. The database is divided into six main sections: systems, weapons, sensors, engineer data, weather data, and chemical and heat data. Each main section has numerous subsections, all requiring inspection prior to creating a scenario to ensure accurate information is provided. A separate Janus database Manager's Manual is available and necessary for reference.

Janus' post-processor permits the analyst to gather detailed results from scenarios. The post-processor offers a variety of detailed statistics, including reports on the number of rounds fired, kill ranges, detection ranges, minefield crossings, chemical

casualties, and Loss Exchange Ratios (LER). The user has the option to select which reports will appear in the post-processor, which precludes generating unnecessary reports while focusing on the area of interest. The reports of interest for this thesis are those reports mentioned above.

2. Janus Uses

Originally designed as an analytical model, Janus is presently used in the Training, Exercises, and Military Operations (TEMO) and the Advanced Concepts Requirements (ACR) domains. Both domains participate as members of the configuration control board to ensure all of the users' requirements are satisfied.

a. Training

Janus is best geared to train leaders at brigade level and below because of its high resolution capabilities. The ability to model down to an individual system enables scenarios to focus on company, platoon, or squad size elements. Commanders at brigade level can use Janus to train the leaders of these elements in the decision-making process. Janus' interactive capabilities allow leaders to make decisions during an engagement, and then to observe the outcome of their actions. Following the scenario, the entire battle can be replayed using the Janus Analyst Workstation (JAWS) and assessed for after-action review purposes.

b. Analysis

Janus is particularly suited for the analyst. Janus' post-processor permits the analyst to gather results from scenarios for further study of topics such as new tactics, techniques, and procedures. The analyst creates scenarios using standard methods, and then compares the results to a scenario using newly proposed methods.

The analyst also uses Janus to study the effects of a new or modified weapon system. Janus' database is robust enough to capture or alter many aspects of a weapon system, including weapon range, detection range, sensor type, travel speeds, and crew size. These weapon systems can also be tested in various environments and weather conditions based on the weapon's mission profile.

As a stand-alone simulation, Janus has aided Army trainers and analyst for years. Janus must now move to the next level of simulation, the DIS environment, in order to remain beneficial to the Army of the 21st century.

B. DISTRIBUTED INTERACTIVE SIMULATION (DIS)

1. DIS Background

The DIS Master Plan defines DIS as "A synthetic environment within which humans may interact through simulation(s) and/or simulators at multiple networked sites using compliant architecture, modeling, protocols, standards, and databases" [Ref. 3:p. I-1]. Leading edge computer technologies and advanced communications networking allow for such an environment to exist. Essentially, DIS is

an environment which brings the power of the computer and communications together to benefit the trainer and analyst.

The terms of DIS are defined as follows: Distributed refers to geographically separated simulations, each hosted on a computer and connected via networks to create a shared environment. Interactive is described as different simulations electronically linked to act together and upon one another. Simulation is divided into three categories: a) live simulation where actual equipment and soldiers are operating in the field, b) constructive simulation which includes wargames and models such as Janus, and c) virtual simulation which involves manned simulators interacting within a virtual reality environment [Ref. 3:p. I-2 - I-3].

The primary objective of the DIS program is to establish an architecture which permits the linkage of different simulation environments into a seamless synthetic world. The infrastructure brings together systems built for separate purposes, technologies from different eras, products from different vendors, and platforms from various services [Ref. 3:p. I-2]. Janus, operating in a DIS environment at Ft. Hood, Texas, linked to a virtual AH-64 Apache simulator at Ft. Hood and a constructive ModSAF simulation at Ft. Knox, Kentucky is a realistic application of the DIS objective (described above).

2. DIS Benefits

Since the development of DIS in 1991 with the successful linking and interacting of the Simulation Network (SIMNET) program, observers have enthusiastically embraced the benefits of DIS. Specifically, a DIS environment can

benefit the Army and other services in the areas of training, combat development, and systems acquisition.

In terms of training, commanders have greater potential to train as they fight. If a DIS capability is established between live and constructive and/or virtual simulations, training will more realistically mirror combat conditions. Another aspect of DIS training benefits is in the area of jointness. An objective of DIS is to link simulations across services. Such a link enhances joint training and promotes increased joint training activities.

DIS provides the combat development community expanded capabilities. First, DIS provides the ability to introduce new simulations into the synthetic DIS environment, such as an individual soldier simulated as a virtual entity, with minimal impact on software. DIS also provides combat developers the capability to collect and record actions and reactions generated by humans with minimal interference from observers [Ref. 3:p. III-4].

The benefit DIS brings to systems acquisition is reduced test and evaluation costs. By linking live, constructive, and virtual simulations, the acquisition life cycle can be reduced significantly, resulting in test and evaluation cost reductions.

The focus of this thesis is evaluating Janus in a DIS environment. The value of Janus and the importance of DIS were the driving forces in the development of JLink, the method by which Janus operates in the DIS environment. The next section highlights the methods of JLink and the challenges faced by JLink.

C. JLINK

1. JLink Background

In 1993, TRAC Monterey began developing the JLink system to support the Anti-Armor Advanced Technology Demonstration (A2ATD). The A2ATD was charged with developing and demonstrating the use of DIS to evaluate anti-armor weapon systems on a combined arms task force. TRAC Monterey had the overall responsibility for building the systems, providing project management, and contributing functional area expertise. Other contributors to the JLink project include the Naval Postgraduate School (NPS), RAND, MITRE, and Rolands and Associates (R&A). NPS and RAND developed the interface between Janus and the World Modeler. RAND also conducted terrain conversions and modified Janus internal algorithms as necessary, while MITRE focused on implementing dead reckoning algorithms. [Ref. 1:p. 1]

Following the A2ATD, TRAC Monterey continued to develop JLink to serve the TEMO and ACR domains with future training and analytical requirements. To assess the state of JLink development, TRAC Monterey conducted a comparison study of Janus to JLink in the summer of 1996. The study applied a rudimentary scenario in a single environment to test basic engagement methodologies. The results of the study showed that JLink produced similar kill ranges and loss exchange ratios when compared to Janus, but statically different shot totals for the blue forces. The cause of the total shots discrepancy was identified as a *z*-coordinate issue with respect to aircraft, and the study concluded that a scenario fought in stand alone Janus is "closely matched" with the same scenario fought under JLink's current configuration [Ref. 4:p. 9-10].

As TRAC continues to develop JLink, recurrent testing is necessary to assess JLink's current state. As JLink evolves into a robust model, capable of simulating multiple battlefield phenomena, comparison studies between Janus and JLink must be diverse enough to test and analyze newly developed aspects of the system. This thesis conducts such a test by simulating large scale scenarios in multiple environments. The experiment also includes recently developed JLink functions such as Family of Scatterable Mines (FASCAM) and chemical artillery.

2. JLink Architecture

This section describes the JLink architecture, which enables Janus to operate in a DIS environment through use of the World Modeler. Network management establishes the connection between Janus and other DIS-compatible models, such as ModSAF, using two different protocols. The Transmission Control Protocol/Internet Protocol (TCP/IP) is used to establish communications between the World Modeler and Janus, while the User Datagram Protocol (UDP/IP) is used to establish communications between the World Modeler and DIS. Through these links, the World Modeler controls dataflow by passing Protocol Data Unit (PDU) information to Janus and DIS at the appropriate time intervals [Ref. 1:p. 5] (Figure 1). The purpose of the PDU is to facilitate the electronic transfer of data between simulations with different software.

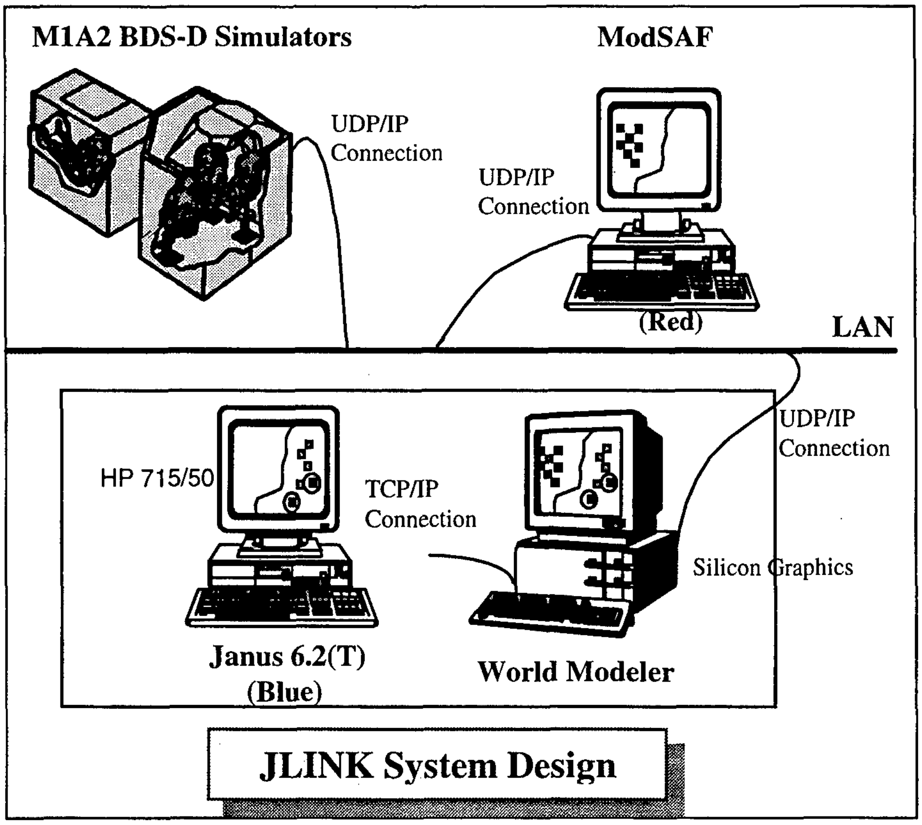


Figure 1. JLink Design

Suppose Janus is portraying Blue forces and a DIS-compatible simulation is portraying Red forces. When Blue generates an event, such as firing at a Red entity, Janus sends a message to the World Modeler via the TCP/IP connection. The World Modeler uses "hooks" to capture the Janus protocol and converts the Janus protocol to a DIS PDU, which can be processed by a DIS model. The World Modeler then broadcasts the DIS PDU via the UDP/IP connection to the network for use by the DIS (Red) simulation. Conversely, when the Red force generates an event, the corresponding DIS PDU is sent via the network to the World Modeler, where it converts the DIS PDU to a Janus protocol, which in turn is sent to the Janus simulation for processing. In essence,

one of the functions of the World Modeler is to convert Janus Protocols to DIS PDUs and vice versa.

Currently, JLink has successfully interacted with several constructive simulations and virtual simulators, via DIS PDUs. However, evolving systems require extensive testing, and the JLink process frequently requires adjustments or model calibration to achieve effective levels of interoperability between interfacing systems.

II. PROBLEM DESCRIPTION

Improved interoperability can be translated into minimizing the distortion between results from Janus stand-alone and the results of the same scenario run in JLink. Two or more simulations/simulators are defined as "DIS interoperable" when their performance characteristics support a fair fight to the fidelity required for the exercise. A fair fight exists when the differences in two simulations' performance are overwhelmed by user actions [Ref. 5:p. A-4]. There are two general factors which may contribute to differences in the results between Janus stand-alone and JLink scenarios and lead to an unfair fight. These factors are the JLink architecture and the DIS PDU itself, which form the basis for the problem description of this thesis. This chapter addresses how JLink architecture and the DIS PDU may contribute to distortion. As part of the problem description, the chapter concludes by identifying specific features of JLink, which may be affected by the factors mentioned above, that require testing.

A. DISTORTION FROM JLINK ARCHITECTURE

Inherent aspects of the JLink architecture may contribute to differences in JLink results versus Janus stand-alone results. Given that Janus is an event-driven model, the sequence of events is vital to the outcome. In stand-alone Janus, a scenario will produce the same sequence of events, and hence the same results, for every run as long as the random number seed remains unchanged and no human interaction occurs. In JLink, delays in passing and converting PDUs may produce a different sequence of events than the corresponding Janus stand-alone scenario. Delays in passing PDUs between DIS

models are a function of network congestion and quality of the network hardware. Delays in converting Janus protocols to DIS PDUs, and vice versa, also contribute to an altered sequence of events. A different sequence of events will result in different outcomes. Say for instance a Blue entity in stand-alone Janus generates a shot event on the event list against a Red entity at time = 10 minutes, resulting in a Red kill at time = 11 minutes. In JLink, the same shot event may not get scheduled until time = 12 minutes due to delays in passing and converting the appropriate PDU, which may result in the Red entity surviving (and shooting) longer than in Janus stand-alone.

Another aspect of JLink architecture contributing to distortion is the issue of random number generators. Janus stand-alone utilizes only one random number generator to determine the outcome of all stochastic events. JLink uses the Janus random number generator to adjudicate only those events corresponding to its own side. The other sides represented in the scenario use their own random number generators to adjudicate stochastic events. Even if all random number generators involved behave identically (which is unlikely) and they are all initiated with the same random number seed, they will not produce the same aggregate random number string as the Janus stand-alone generator for an entire scenario. Dissimilar random number strings will result in dissimilar results between Janus stand-alone and JLink.

This thesis will not attempt to determine whether any JLink architecture issues like those above contributed to distorted results. The thesis experiment did, however, reduce the impact of the architecture on results by using the following procedures. To reduce interference when passing PDUs, all JLink runs were executed during times when the TRAC Monterey network was free from all other activity. Also, all scenarios run in

JLink used the same random number seeds used in Janus stand-alone. Using the same random number seeds will produce some of the same random numbers for both JLink and Janus stand-alone scenarios.

B. DISTORTION FROM DIS PDUs

One major challenge to World Modeler developers is to accurately translate and create DIS PDUs as they flow to and from the Janus model. The DIS PDUs created by the World Modeler for use by other distributed systems must portray the originating Janus protocol as accurately as possible. Likewise, DIS PDUs sent to the World Modeler by distributed simulations must be translated appropriately for use by Janus. Inaccurate or inappropriate conversions of PDUs may produce distorted JLink results as compared to the Janus stand-alone standard.

One example where appropriate conversions of PDUs is critical is the flight altitude of rotary-wing aircraft. Janus only portrays two flight levels, treetop level (low) and at altitude (high), whereas ModSAF simulates continuous altitudes. The issue becomes at which flight level a ModSAF helicopter entity should be simulated in Janus, and at what altitude a low flying Janus helicopter should be simulated in ModSAF.

In order to test for distortion caused by the DIS PDUs, JLink requires additional testing of a wide variety of features. To date, JLink fidelity has only been tested using rudimentary scenarios in a single environment. JLink development is now at the stage which can support testing of additional aspects of the system.

C. JLINK FEATURES TESTED IN EXPERIMENT

1. Varied Scenarios

One aspect of the JLink system this thesis tests is JLink's ability to accurately portray different types of combat units in the offense or defense, negotiating obstacles, under different environmental conditions. Such scenarios have yet to be validated using JLink. If JLink operates as designed, the results from these varied scenarios will be similar to the results of the same scenarios run in stand-alone Janus.

2. Coalition Warfare

The thesis experiment also includes an assessment of JLink simulating the synergistic effects of coalition warfare. Previous tests involving JLink have only included two sides fighting against one another. As part of the experiment, one scenario includes three sides, two forces allied together fighting against the third. Pitting two sides against a lone third side may generate insightful results regarding JLink's ability to accurately fight a coalition battle.

3. Specific Combat Functions

In addition, the thesis tests whether JLink accurately portrays the effects of specific combat functions. Recent JLink software inputs, designed to replicate specific combat functions such as chemical artillery delivery methods and FASCAM, require testing. In stand-alone Janus, chemical artillery volleys are delivered as an aggregated threat, with one large radius. DIS standards require that individual artillery rounds be

passed between simulations. Because of this requirement, programmers have modeled a JLink chemical artillery volley as having each round create its own radius of effect. Figure 2 depicts a volley of three artillery rounds and illustrates the difference in the two delivery methods.

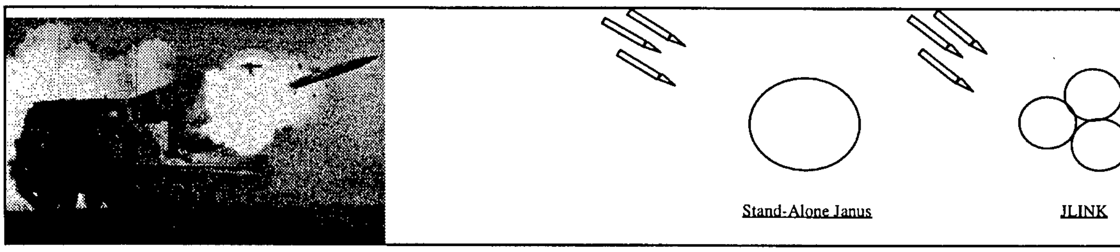


Figure 2. Artillery Delivery Methods

The thesis will determine whether such a distribution of chemical artillery rounds significantly affects the number of kills.

Another specific combat function requiring testing is FASCAM, an artillery-delivered minefield. Unlike chemical artillery, aggregation is not an issue regarding FASCAM. This thesis provides initial feedback on the FASCAM code as to whether it generates the same number of kills as FASCAM in stand-alone Janus.

Herein lies the goal of this thesis – to assess JLink fidelity by testing whether JLink produces similar results to stand-alone Janus using varied scenarios and coalition warfare, and by determining whether recent software inputs to specific combat functions are providing accurate representations.

III. DESIGN OF EXPERIMENT

The overall goal of the experiment was to provide a means to obtain data from a scenario executed in Janus and the same scenario executed in JLink for purposes of analysis. The issues involved in meeting the goal were selecting appropriate data to be analyzed, determining the structure of the scenarios, and conducting the experiment. This chapter begins by presenting the measures of performance and the methodology supporting their selection. Next, details of the scenarios are described, followed by a discussion of the conduct of the experiment and issues encountered with the execution. The experiment included necessary conditions for testing the issues defined in Chapter II.

A. MEASURES OF PERFORMANCE

The first issue in designing the experiment was to identify what data would be analyzed. The MOPs were limited only by the information provided in the post-processor. For clarity, this thesis refers to the data as measures of performance, as opposed to measures of effectiveness. The reason for the distinction is that the purpose of the thesis is not to analyze the effectiveness of a new weapon system or perhaps a tactic. Rather, the focus is to assess JLink fidelity by comparing the performance of the JLink system to the performance of the stand-alone Janus system.

The MOPs were derived from issues raised in the Problem Description. The areas that require testing in JLink are varied scenarios, meaning scenarios using different types of units in contrasting environments, coalition warfare, and specific combat functions such as chemical artillery and FASCAM. The determination whether JLink accurately

portrays the areas defined in the Problem Description is derived from the analysis of one or more of the following MOPs: 1) Detection Ranges, 2) Kill Ranges, 3) Rounds Fired, 4) Loss Exchange Ratio (LER), 5) Chemical Artillery Kills, and 6) FASCAM Kills.

1. MOPs for Varied Scenarios and Coalition Warfare

To determine the fidelity of varied scenarios in JLink, the thesis analyzed detection ranges, kill ranges, rounds fired, and LER. Applying appropriate MOPs to the broad topic of scenario fidelity is critical to arriving at valid conclusions. The analysis must focus on the basic procedures of an engagement. First, one entity must detect another entity. Comparing the detection ranges of Janus stand-alone and JLink is a quantitative method of assessing the detection process in JLink. Next, the detecting entity may elect to shoot at the target, possibly resulting in a kill. Analyzing the kill ranges between Janus and JLink is a quantitative method for assessing the killing process in JLink. Since not all shots result in kills, the total number of rounds fired must also be analyzed. The post-processor also provides the flexibility to analyze detection ranges, kill ranges, and rounds fired for an entire scenario or by individual side. For instance, rounds fired can be analyzed by comparing total Janus rounds fired to total JLink rounds fired for the same scenario, or by comparing blue Janus rounds versus blue JLink rounds.

Detecting and killing the target are the basic elements of a battle. If JLink replicates these functions in the likeness of Janus, one would expect similar overall outcomes between Janus stand-alone and JLink scenarios. Further, since LERs are primarily a function of detections and kills, the LERs offer a quantitative method to assess the overall outcome of a JLink scenario.

2. MOPs for Chemical Artillery and FASCAM

To determine whether JLink achieves acceptable results from chemical artillery and FASCAM, the thesis analyzed the number of kills generated by chemical artillery and the number of kills resulting from firing FASCAM.

B. SCENARIOS

The scenarios were determined based on the Problem Description requirements. Specifically, the thesis must analyze results from varied scenarios, coalition warfare, and the specific combat functions of chemical artillery and FASCAM. US and Russian-style armored and light infantry units, along with their supporting elements, were a logical selection for the unit types. Armored and light infantry units are combat arms likely to be involved in offensive or defensive operations. Units equipped with US- and Russian-made weapons bring diverse capabilities to the battlefield, adding robustness to the study.

In determining the environments, the goal was to select two contrasting locations which will likely have different effects on detection ranges and engagement ranges. The two contrasting environments used were Southwest Asia (SWA) and Hunter Liggett, California (HL). SWA is primarily desert with no trees and slightly undulating terrain, which provides some relief. HL is comprised of small hills and lightly wooded terrain. The relatively flat terrain of SWA compared to the rolling, wooded terrain of HL offers contrasting settings to test sensor functions and weapons platforms.

After determining the types of units and environments, the final element in the scenario structure was the means of engagement. The engagement used was an attacking

battalion against a defending company. Such an engagement provided results from units with contrasting postures, moving as opposed to stationary. Different postures affect the detection and firing capabilities of entities in Janus.

Once all of the elements of the scenarios were identified, three scenarios were developed. The first scenario involved a US-equipped armored company (blue) defending against an attacking Russian-equipped armored battalion (red). The second scenario was identical to the first, except that the red force was divided into two sides to form a coalition. The red coalition attacked the (defending) blue force to test the results of a coalition engagement, in both a stand-alone and distributed mode. The third scenario involved a US-equipped light infantry company (blue) defending against an attacking Russian-equipped light infantry battalion (red). In every scenario, the blue side fired chemical artillery rounds and FASCAM at specifically identified red units traveling on a narrow avenue of approach. This was done to isolate the weapons' performance to aid in the deconfliction of MOPs for analysis. Also, all blue sides possessed obstacles to aid in the defense. The obstacles included minefields and abatis for road barriers.

1. Scenario 1

The weapon systems used by the blue side in scenario 1 were the M1A1 tank, M2 Infantry Fighting Vehicle (IFV), Multiple Launcher Rocket System (MLRS) artillery, AH64 Apache helicopter, and four riflemen as scouts. The red side consisted of the T72 tank, BMP-2 IFV, MLR16 (MLRS equivalent), Hind helicopter, and SA14 air defense weapon. The blue side consisted of 32 total units (mainly M1A1s), while the red side had 91 total units (mainly T72s), resulting in approximately a 3:1 ratio in favor of the

attacker. The scenario was designed to emphasize the capabilities of the M1A1 and T72 tanks, with support from the other systems.

2. Scenario 2

The weapon systems, weapon numbers, and scenario design in scenario 2 were identical to those in scenario 1. In scenario 2, the red force was divided into two sides, fighting together as a coalition against the blue force.

3. Scenario 3

The weapon systems used by the blue side in scenario 3 were the rifleman with M16 rifle, rifleman with machine gun, Light Anti-tank Weapon (LAW), mortars, and MLRS. The red side consisted of the rifleman with AK47 rifle, rifleman with machine gun, anti-tank RPG, mortars, and MLR16. The blue side had 116 units *versus* 653 units for the red side, resulting in a 5.6:1 edge in favor of the attacker. The scenario emphasized the capabilities of the rifle and machine gun.

4. Scenario General Characteristics

Red forces attacked from north to south in all scenarios since likely avenues of approach in both environments favored north-south attack routes. Recall that blue forces fired chemical rounds at specific red units to assess their effectiveness in distributed simulations. Since the wind generally travels from southeast to northwest in both environments, it was logical to have the blue side firing northward, or downwind. Hence, the red forces were arrayed to attack south.

Another common characteristic between scenarios was the placement of the blue forces. All blue units were placed on relatively defensible terrain, oriented to the north. Ensuring the blue units had adequate Line of Sight (LOS) to the north was critical to the defense. Figure 3 shows the Janus map of HL, with the blue units in position. The figure also shows the LOS of one blue entity, with "blind spots" shown as broken radials.

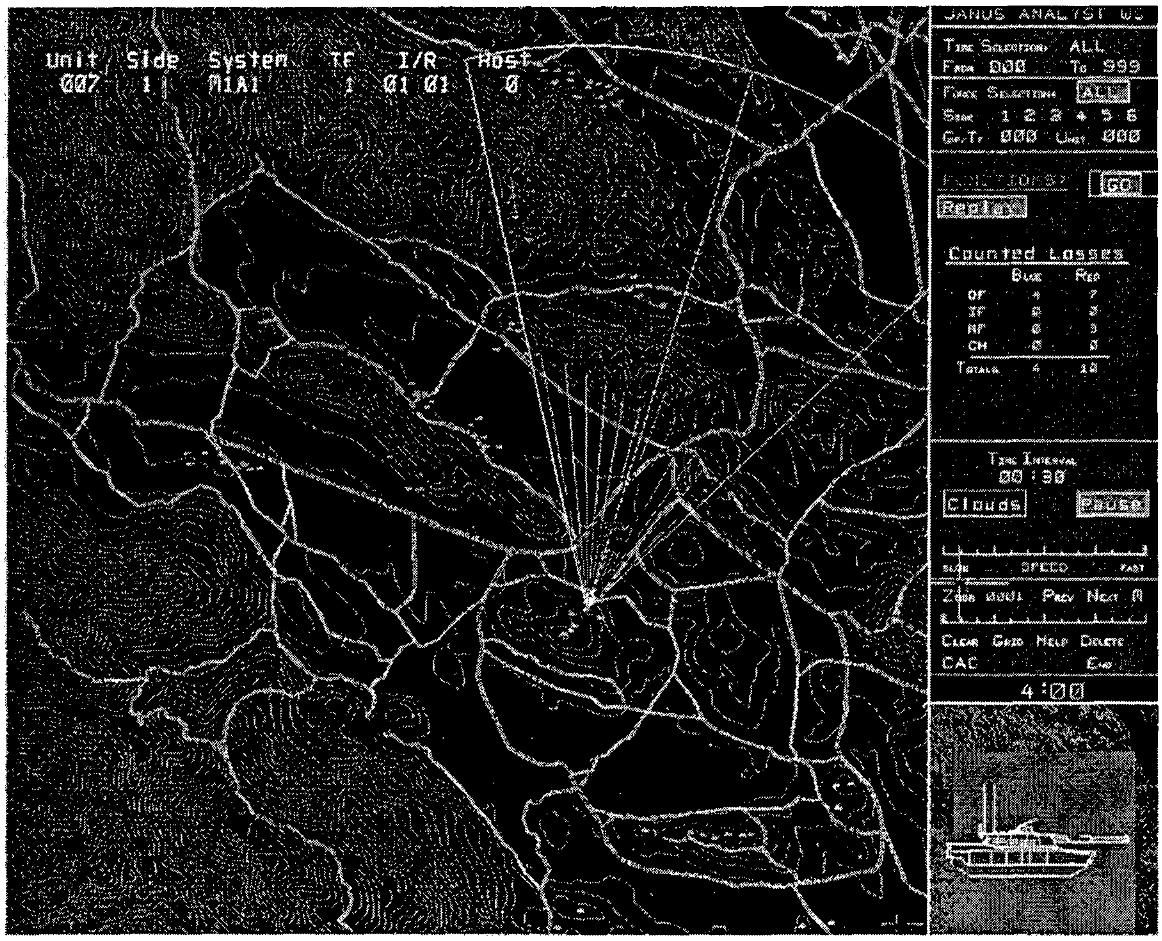


Figure 3. Scenario Graphics

Additionally, the scenarios were designed so that all blue entities could fire at all red entities, and vice versa. This design required slight adjustments to the database in

some instances. The purpose of this design was to test JLink's ability to portray multiple types of weapons engaging each other.

Finally, all scenarios lasted between 17-27 minutes, with the average length being approximately 20 minutes. Although the test scenario is short compared to typical Janus exercises, which often last several days, 20 minutes permitted artillery units to fire assigned volleys, "pucked" FASCAM to fire five minefields, aircraft to fly designated routes, and attacking elements to move into and through the engagement area.

C. EXPERIMENT

1. Conduct of Experiment

Each of the three scenarios were executed in two environments, SWA and HL, resulting in six combinations. Each combination was then run in two different modes. First they were run in the Janus stand-alone mode, Janus (blue) versus Janus (red), with both the blue and red forces simulated on the same Hewlett-Packard (HP) workstation. Then the same six combinations were run in the JLink (blue) versus JLink (red) mode, with the two forces simulated on separate workstations, as illustrated in Figure 4. The JLink versus JLink mode is the method developed at TRAC Monterey to test distributed Janus without having to connect to another type of DIS simulation. Each Janus terminal is connected to a World Modeler which in turn is connected to the network.

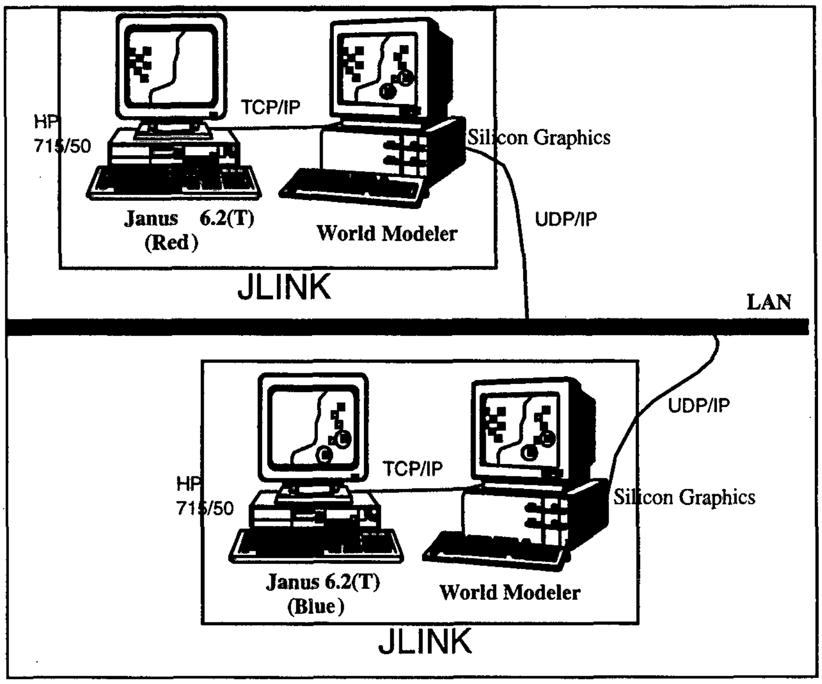


Figure 4. JLink vs JLink

Six combinations run in two different modes resulted in 12 total combinations in order to capture all scenarios, environments, and modes. Figure 5 depicts the overall experiment.

	Janus Stand-Alone	JLink vs JLink
Armored SWA Armored HL	(avg of 10 runs) (avg of 10 runs)	(avg of 10 runs) (avg of 10 runs)
Armored Coalition SWA Armored Coalition HL	(avg of 10 runs) (avg of 10 runs)	(avg of 10 runs) (avg of 10 runs)
Light Infantry SWA Light Infantry HL	(avg of 10 runs) (avg of 10 runs)	(avg of 10 runs) (avg of 10 runs)

Figure 5. Overall Experiment (Averages for Specific MOP)

These 12 combinations, however, only provide one data point for each

MOP, and will be referred to as a single run of the experiment. Ultimately, 10 runs were performed for each cell to provide a reasonable sample. (The issue regarding the total number of runs is addressed in Chapter III, paragraph C. 2.)

The desired method of analysis was to compare the MOPs resulting from a specified number of Janus stand-alone runs to the MOPs resulting from the same number of JLink runs. Since a stand-alone run will produce the exact same results if the same random number seed is sown, all stand-alone runs were executed using different, randomly selected, seeds. The same random number seeds were then used in the corresponding JLink runs. Also, due to the inherent variability caused by JLink architecture, 10 additional runs were performed in JLink using the same random number seed for all 10 runs to isolate the variance contribution from that aspect of the JLink system.

2. Experiment Issues

As mentioned previously, all JLink runs were done during times of minimal traffic on the TRAC Monterey network. In all but four JLink runs, the scenarios were executed when the network was completely free of other users. Executing the scenarios with minimal network interference reduces variability in the results due to event scheduling. If the network is congested, delays may occur in passing information and the sequence of events may be affected.

Determining the sample size is fundamental to the design of every experiment. An experiment is conducted a number of times so that the data produces good estimators of the true population parameters. Different techniques are available to arrive at a

satisfactory sample size. The thesis proceeded as follows regarding this issue. First, a practical approach was used. Based on experience and recommendations from senior Janus analysts, a sample size of n = 10 generally produces results with "acceptable variance" for the MOPs defined in this thesis. That is, the experiment is run until an estimate of the variance for the mean is reduced to a pre-determined, acceptable level. This level will be different for each measure of performance. Based on the raw data figures in Appendix A, acceptable variance was achieved in detection ranges, kill ranges, LERs, and for most cases of rounds fired. Discussion in Chapter IV highlights anomalies in FASCAM and chemical kills which preclude the possibility of reaching acceptable variances levels for these MOPs with reasonable sample sizes.

The thesis also considered the issue of normality of the data when determining sample size. Normality of the data set is one assumption in the two sample *t*-test, which is used for analysis of the MOPs. The normal distribution quantile plots in Appendix F show that the results for most MOPs are relatively normal, with some obvious exceptions. Also, the *t*-test normality assumption is generally satisfied if the sample averages are normally distributed. As the sample size increases, one would expect the sample averages to become more normal, based on the Central Limit Theorem [Ref. 6:p. 232]. In this case, we expect a sample size of n=10 to be large enough to produce normally distributed averages.

Another issue addressed prior to beginning the runs was that the user can only fire FASCAM while the scenario is on-going. The users timing and accuracy could vary significantly from run to run and thus alter the FASCAM results. The solution was discovered in the "puck" run. In essence, a puck run records all of the actions of a

previously run scenario, including the user actions, and replays them on the current scenario run. By pucking the initial run of each scenario, then changing the random number seeds for the following runs, the user can replicate the same scenario, to include FASCAM volleys, while generating different results due to the new seed.

The final issue encountered in conducting the experiment occurred after the runs were complete. The issue involved gathering the information from the post-processor into a usable form. After transferring the post-processor information to a personal computer, extensive manipulation of the data was required prior to importing the data into a spreadsheet or statistical package. Since the results from the post-processor are lengthy and involve thousands of numbers in the case of these scenarios, manipulating the data was cumbersome and occasionally resulted in lost data. To resolve the issue, a C program was written and used as a filter to easily gather the required data for the MOPs.

IV. DATA ANALYSIS

This chapter presents the methodology for analyzing the results, the statistical tests used in the analysis, and the results from the analysis. The following chapter provides a detailed analysis of the results presented in this chapter.

A. ANALYSIS METHODOLOGY

After running the 12 combinations described in Figure 5, with 10 replications for each cell, summary statistics for each MOP were gathered. The raw data for the experiment is presented in Appendices A, B, and C. The LER is the total red entities killed divided by the total blue entities killed. Each data entry for detection range and kill range is the average of all detection ranges (kill ranges) for the specified mode on the given run. The rounds fired data is the total of all direct fire rounds shot for the specified mode on the given run.

The data was then analyzed by MOP. First, the Analysis of Variance (ANOVA) test was used to determine if differences existed between the means of the Janus population and the JLink population for the given MOP. ANOVA determines whether sample means from different populations are statistically similar by analyzing the ratio of the variance estimates. ANOVA also helps identify interactions occurring between the three factors of the experiment – scenario type, environment, and mode (Janus/JLink) – with respect to the given MOP.

The ANOVA test identifies whether their are differences in the means between the two populations, but does not indicate where the difference occurred. To identify where the differences in the means exist, a pair-wise two sample *t*-test was applied to

those MOPs whose populations were deemed statistically different by the ANOVA. In this case, the goal was to determine whether the results, from an MOP in a specific scenario and environment executed in Janus stand-alone, are statistically similar to the results of the same MOP under the same conditions executed in JLink. Such a pair-wise comparison highlights where differences in the means exist.

For this thesis, the sample size is relatively small and the population variances are unknown, hence a two sample *t*-test is appropriate in this case. [Ref. 6:p. 357-359]. The assumptions for the two sample *t*-test are:

1. Both samples are independent random samples from normal populations.
2. The two populations have equal variance.

Data sets were analyzed to determine whether assumptions were satisfied prior to applying the *t*-test.

In cases where the assumptions were not satisfied, the data was analyzed in the same pair-wise method using the less powerful Mann-Whitney-Wilcoxon (Wilcoxon) nonparametric test. The Wilcoxon test does not require that the data satisfy the normality assumption above. The Wilcoxon test was also performed on the MOPs which did satisfy the assumptions to further substantiate the results of the *t*-test.

The data analysis concludes with a discussion of the variability within the JLink system to determine if the main contributor to variance comes from within the JLink system or from within the simulation runs.

B. TOOLS FOR ANALYSIS

1. ANOVA

The ANOVA determines whether sample means from different populations are statistically similar and identifies interaction between factors. The design of the experiment resulted in the data being organized into a 3 x 2 x 2 fashion, meaning the experiment tested three factors, the first involving three levels, and the second and third factors involving two levels (Figure 5). The first factor, scenario type, was tested at three levels: armored, armored coalition, and light infantry. The second factor, environment, was tested at two levels: SWA and HL. The third factor, mode, was tested at two levels: Janus stand-alone and JLink. The first and second factors were blocking factors, while the third factor acted as the treatment factor which this thesis intended to analyze.

An interpretation of the ANOVA table follows. Table 1 shows the results of the ANOVA for detection ranges by the blue forces.

Analysis of Variance Table for Detection Range Blue
Response: MOE (Detection Range Blue)

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	95.34164	47.67082	6050.279	0.0000000
Env	1	2.51797	2.51797	319.576	0.0000000
Mode	1	4.11438	4.11438	522.188	0.0000000
Scen:Env	2	0.19275	0.09638	12.232	0.0000163
Scen:Mode	2	1.64627	0.82313	104.470	0.0000000
Env:Mode	1	0.09369	0.09369	11.892	0.0008050
Scen:Env:Mode	2	0.00861	0.00431	0.547	0.5805110
Residuals	108	0.85094	0.00788		

Table 1. ANOVA Results for Blue Detection Ranges

The ANOVA table provides results for analysis of blocking factors, scenario type and environment, and the treatment factor, mode (Janus/JLink). The focus of the thesis is on the treatment factor, mode, to assess whether Janus and JLink produce similar results for

given MOPs. The highlighted row, labeled Mode, is interpreted as follows. The ANOVA model equation for Y_{ijk}, the observation recorded for the *i*th scenario, and *j*th environment, and *k*th mode, is

$$Y_{ijk} = \mu + \beta_i + \tau_j + \gamma_k + \varepsilon_{ikj}$$

where μ is the overall mean

β_i is the effect of the *i*th treatment

τ_j is the effect of the *j*th environment

γ_k is the effect of the *k*th mode

ε_{ijk} is the experimental error ~ Normal $(0, \sigma^2)$,

and it is initially assumed that there is no interaction between factors [Ref. 7: p. 532]. In words, the recorded observations for Blue Detection Ranges, separated by mode, (highlighted row above) are interpreted as follows:

Janus Blue Det Rng = overall mean Blue Det Rng + ScenEffect + EnvEffect + JanusModeEffect + error.

Similarly, every JLink recorded observation is interpreted as follows:

JLink Blue Det Rng = overall mean Blue Det Rng + ScenEffect + EnvEffect + JLinkModeEffect + error.

Assuming the model is additive, subtracting the JLink equation from the Janus equation returns a model which isolates the MOP in terms of the mode effects (and error):

Janus MOP - JLink MOP = Janus Mode Effect - JLink Mode Effect + error.

In this case, the zero p-value in the Mode row means that the null hypothesis

$$H_o\text{: } \textit{mean Janus Blue Det Rng} = \textit{mean JLink Blue Det Rng}$$

is strongly rejected. The ANOVA does not, however, identify where the difference occurred.

Figure 6 shows interaction plots for scenario:environment, scenario:mode, and environment:mode for the same MOP, blue detection ranges. The interpretation of the scen:mode interaction is as follows. The null hypothesis tested is

$$H_o: \left.\begin{array}{l} AvgJanusBlueDetRng - AvgJLinkBlueDetRng = \Delta, scen\#1 \\ AvgJanusBlueDetRng - AvgJLinkBlueDetRng = \Delta, scen\#2 \\ AvgJanusBlueDetRng - AvgJLinkBlueDetRng = \Delta, scen\#3 \end{array}\right\} All\Delta's \text{ the same.}$$

In this case, the p-value for scen:mode interaction is zero, thus rejecting the null hypothesis. This result can be interpreted as saying, not only are the sample means for blue detection ranges different between Janus and JLink, the difference varies between scenario. Figure 6 highlights with arrows where the difference in means are considerably larger between Janus and JLink for scenario #1 compared to the difference in scenario #3.

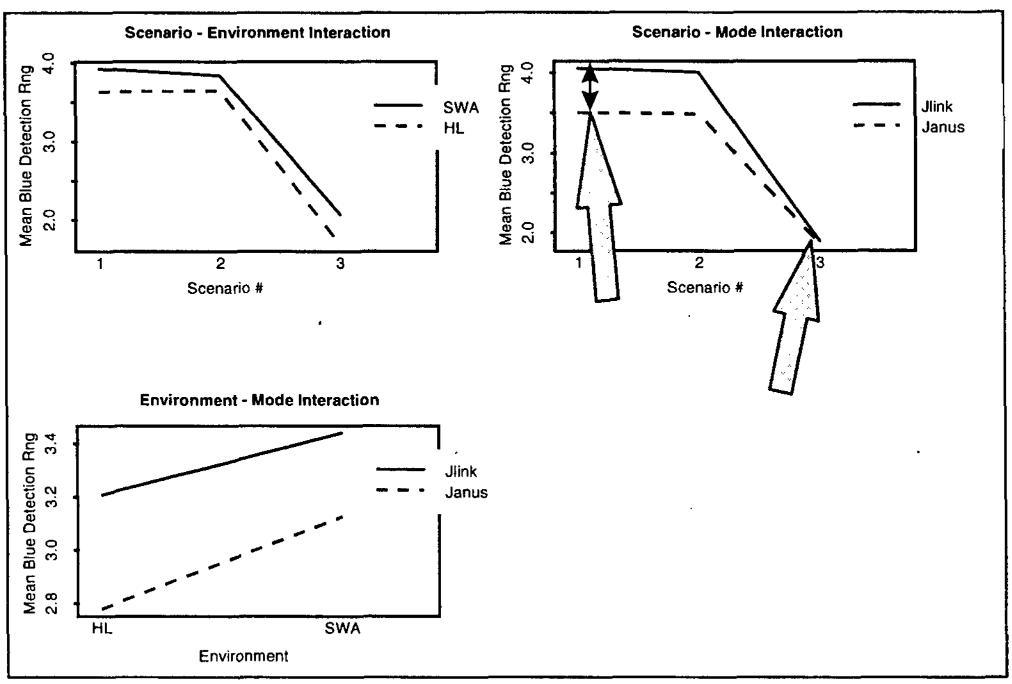


Figure 6. Interaction Plots for Blue Detection Ranges

The value of the interaction plots for this thesis is that they provide insights as to the cause of disparate results between Janus and JLink. For instance, the scen:mode

interaction plot shows that greater differences in blue detection ranges occur in armored and armored coalition scenarios as compared to light infantry scenarios. This finding indicates that situations peculiar to armor and armor coalition scenarios contribute most to the gap in blue detection ranges between Janus and JLink.

2. Two Sample *t*-Test

a. Test Description

The two sample *t*-test tests the following hypothesis:

$$H_o: \mu_x - \mu_y = \Delta,$$
$$versus \;\; H_a: \mu_x - \mu_y \neq \Delta.$$

In this case, the thesis determines whether the two sample averages are statistically similar, so our $\Delta = 0$. The test statistic used is

$$t = \frac{\bar{x} - \bar{y} - \Delta}{s_p\sqrt{\frac{2}{n}}},$$

where s_p is the pooled sample variance, defined at the beginning of this chapter, and $\bar{x}$ and $\bar{y}$ are the two sample averages. The test statistic is then compared to the critical value for a two-sided test. The null hypothesis is rejected if

$$t \geq t_{\alpha/2,2n-2} \text{ or } t \leq -t_{\alpha/2,2n-2}.$$

One method used to determine the confidence level α, when several *t*-tests are conducted, is the Bonferroni method. Essentially, the Bonferroni method divides the original α value, in this case 0.05, by the total possible number of *t*-tests conducted [Ref. 8:p. 424]. This method offers a technique for placing a tighter restriction on the

rejection region of the null hypothesis, which would be otherwise rejected 5% of the time simply by chance if the original α was used. When the *t*-test was applied to an MOP, six different pair-wise tests were necessary to encompass three scenarios executed in two environments. Since a total of 6 comparisons were conducted, the new confidence level used for these *t*-tests was

$$\alpha_{new} = \alpha_{old} / 6 = 0.0083.$$

b. Methods for Testing Assumptions

Before applying the two sample *t*-tests, the assumptions of normality and common variance between sample populations were considered. Two tests were conducted to determine if the assumption of normality was satisfied. First, Quantile-Quantile Plots (Q-Q Plots) for the normal distribution were plotted. The results are shown in Appendix F. The population is considered normally distributed if the plot produces a generally straight line.

The Kolmogorov-Smirnov (KS) Goodness of Fit (GOF) was also used to test for the normality assumption. The test determines if a sample population follows a prescribed distribution. The KS GOF tests the following hypothesis:

$$H_o\text{: Sample Population} \sim \text{Normal}\ (\bar{x}, s^2)\text{, } \textit{versus}$$

$$H_a\text{: True cdf does not equal normal distribution for at least one sample point.}$$

For small sample sizes, such as 10, the KS GOF rarely rejects the null hypothesis at a α=0.05 level of significance. Because of this fact, the KS GOF was used as a secondary method to test for normality after visually inspecting the Q-Q Plots. The results of the KS GOF are found in Appendix G, with highlighted areas being those MOPs with p-values

less than 0.05, which rejects the null hypothesis. The p-value is the smallest level of significance at which H_o would be rejected when a specified test procedure is used on a given data set [Ref. 6:p. 334]. In general, the results of the test concur with the findings from the Q-Q Plots.

The next assumption required for the two sample *t*-test is that both samples have a common variance. The test used to check the variance assumption was the *F*-test for common variances. The test determines if the ratio of the variances is equal to one. In this case, a two-sided *F*-test is used with a α=0.05 level of significance. The hypothesis tested is

$$H_o: \frac{\sigma^2_{JanusMOP}}{\sigma^2_{JLinkMOP}} = 1,$$

$$versus,\ H_a: \frac{\sigma^2_{JanusMOP}}{\sigma^2_{JLinkMOP}} \neq 1.$$

The results of the *F*-test are in Appendix H, with the highlighted portions being those MOPs which rejected the null hypothesis at the α=0.05 level of significance and did not satisfy the common variance assumption.

For MOPs detection range, kill range, and rounds fired, the *t*-test was applied regardless of the status of the assumptions in order to provide confidence intervals for further analysis. The resulting confidence intervals and p-values are found in Appendix I.

c. Power of the Two Sample *t*-Test

Power is defined as the probability of rejecting a false null hypothesis [Ref. 8:p. 79]. The power of the *t*-test is the probability of detecting an acceptable difference Δ, in the sample means for each MOP. In terms of the null and alternative hypothesis, power is the probability of rejecting

$$H_o : \Delta = 0,$$

in favor of

$$H_a : \Delta = \text{predetermined value},$$

for any true H_a.

The power of the two-sample *t*-test is a function of the sample sizes n and m, the significance level α, the population standard deviation σ, and the real difference between the sample means Δ [Ref. 7 :p. 354, 394]. In this study, all scenarios were run an equal number of times; therefore the sample sizes were n = m = 10 for each MOP. The chosen significance level is α = 0.05. Using the assumption that the two populations from which the MOPs are drawn have a common standard deviation σ, the pooled sample standard deviation is used to estimate σ as follows:

$$s_p = \sqrt{\frac{s^2{}_{JanusMOP} + s^2{}_{JLINKMOP}}{2}}, \text{ (since n = m).}$$

Determining the real Δ, or the value of the difference between means that is considered significant, is rather subjective. For FASCAM kills and chemical kills, a 10% difference would generally be acceptable between the Janus stand-alone and JLink results. A total of 10 units were sent through the FASCAM minefields for all scenarios,

resulting in a value of $\Delta = 1$ for FASCAM. A total of 20 units were sent through the chemical artillery for scenarios 1 and 2, and 200 units (due to aggregation of infantry) were sent through chemical artillery for scenario 3. This results in a value of $\Delta = 2$ for chemical artillery in scenarios 1 and 2, and $\Delta = 20$ for scenario 3. The accepted difference in mean LERs is 0.3. This difference is based on the expected attrition of each scenario and the impact such a difference would make on the outcome of the battle. The accepted difference in the mean rounds fired is approximately 20% of the total Janus rounds fired for each scenario.

The accepted difference in mean detection ranges and kill ranges is 5% of the predominant weapon's capabilities. The predominant weapon is defined as the most widely used weapon in the scenario, in this case the tank for scenarios 1 and 2, and the rifle for scenario 3. The maximum detection range for the tank and rifle is six and two kilometers respectively, resulting in a $\Delta = 0.3$ for scenarios 1 and 2, and a $\Delta = 0.1$ for scenario 3. The maximum kill range for the tank is four kilometers, while the rifle has a kill range of one kilometer. This results in a $\Delta = 0.2$ for killing ranges in scenarios 1 and 2, and $\Delta = 0.05$ for scenario 3. The rationale for selecting 5% for the killing range follows. Assuming the tank travels at 20 kilometers per hour, then a 5% difference in killing range results in an additional killing range of 0.2 kilometers, or additional standoff time of 0.6 minutes. Since a tank is able to fire four rounds per minute, an acceptable difference of two additional rounds will be fired by either the Janus tank or JLink tank.

The next step in determining the power is to calculate ϕ, the non-centrality parameter as follows:

$$\phi = \frac{\Delta}{\sigma_{\hat{\Delta}}}\left(\frac{1}{\sqrt{2}}\right),$$

where $\sigma_{\hat{\Delta}}$ is the standard deviation of the sample estimator for Δ [Ref. 7: p. 355, 394].

Further,

$$\sigma_{\hat{\Delta}} = \sigma\sqrt{\frac{2}{n}}.$$

This equation illustrates that as sample size increases, ϕ also increases, and likewise the power of the test.

Appendix D shows the values required to calculate power. Table 2 shows the calculated power values for each MOP by scenario and environment. The power is determined by entering the noncentral T chart at the appropriate ϕ-value, using 18 degrees of freedom (since two means were estimated from 20 total data points), and reading the corresponding power value [Ref. 7:p. 355]. So, for example, our sample of size 10 ought to detect a 20% difference in "rounds fired" about 54% of the time (Table 2, Scenario #1, SWA). The results in Table 2 show that the experiment produces power values greater than 50% of detecting a difference Δ in the sample means for most MOPs. Also, power values for detection ranges and kill ranges are approximately 70% or greater in most scenarios. Power values in the ranges noted above are generally sufficient for analysis of combat simulations.

Scenario #1, SWA						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	1.00	1.00	.72	1.00	.88	.54
Scenario #1, HL						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	.31	.81	.54	1.00	.93	.29
Scenario #2, SWA						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	.28	1.00	.83	1.00	.56	.25
Scenario #2, HL						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	.40	.88	.62	1.00	.94	.40
Scenario #3, SWA						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	.40	1.00	.40	1.00	.69	1.00
Scenario #3, HL						
	FASCAM	Chem Kills	LER	Det Rng	Kill Rng	Rnds
Power	.72	1.00	<.20	1.00	.31	.986

Table 2. Power Values for MOPs

3. Wilcoxon Test

To substantiate the results of the two sample *t*-test and to test those MOPs which did not satisfy the *t*-test assumptions, the less powerful Mann-Whitney-Wilcoxon (Wilcoxon) nonparametric test was applied to compare the sample means. The Wilcoxon test uses the same two-tailed hypothesis test as the two sample *t*-test. The nonparametric test does not require that the data satisfy assumptions of normality and common variance.

The Wilcoxon test begins by rank-ordering all samples from both populations and assigning ranks 1 through m+n (20 in this case) to all values. If sample values are exactly equal, each value is assigned the average of the ranks that would have been assigned had there been no tie. The test statistic is found by first finding the sum (S) of the ranks assigned to the observations from the first population. The test statistic is given by

$$T = S - \frac{n(n+1)}{2}.$$

The test statistic is then compared to the critical value for a two-sided test. The null hypothesis is rejected if

$$T < \omega_{\alpha/2} \text{ or } T > \omega_{1-\alpha/2},$$

where $\omega_{\alpha/2}$ is the $\alpha/2$ quantile of T [Ref. 9:p. 224-226]. Conover [Ref. 9: Table 8] provides a table of critical values for various quantiles of T. The confidence level α is determined using the same Bonferroni method applied in the *t*-test. As with the *t*-test, the confidence level used was

$$\alpha_{old} / 6 = 0.0083.$$

C. ANALYSIS OF MOPs

The data set used to analyze FASCAM kills, chemical kills, and LERs is found in Appendix A. The MOPs detection range, kill range, and rounds fired were analyzed by side (Appendix B) to provide a clearer interpretation of the results and additional information to whether JLink is accurately simulating units performing a specific type of mission, in this case attacking and defending.

As previously mentioned, the methodology of analyzing the MOPs began with the ANOVA test. The ANOVA considers all three factors in the experiment at all levels to determine if the sample mean of a particular MOP in Janus is statistically similar to the sample mean of the same MOP in JLink. The results of the ANOVA tests in Appendix E conclude that significant differences exist in the sample means between the two modes, except in the instance of red rounds fired. These results indicate that the multiple factors in the experiment cause sample means to be different when analyzed as a whole. The reasons for the differences are initially apparent after inspecting the raw data in Appendices A and B. Specifically, Janus and JLink produced significantly different chemical kills for every scenario, and detection ranges and kill ranges are consistently larger for JLink. Given these disparate inputs to the ANOVA test, one would expect the test to generate statistically different sample means between the two modes. To provide further insight to the particular differences between Janus and its distributed counterpart, the analysis proceeded by identifying significant interactions between factors for each MOP and applying the pair-wise two sample *t*-test and Wilcoxon test to determine where differences existed, leading to recommendations for improvements to JLink.

1. FASCAM

FASCAM was tested using the results in Table 3.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average Variance Stand Dev	2.7 2.68 1.63	2 1.33 1.15
Armored HL	Average Variance Stand Dev	2.9 2.99 1.73	1.5 .72 .85
Armored Coalition SWA	Average Variance Stand Dev	2.3 2.68 1.63	1.5 1.61 1.27
Armored Coalition HL	Average Variance Stand Dev	2.6 2.49 1.58	.6 .27 .52
Light Infantry SWA	Average Variance Stand Dev	1.1 2.54 1.60	.2 .4 .63
Light Infantry HL	Average Variance Stand Dev	1 1.11 1.05	.6 .27 .52

Table 3. FASCAM Results

First, the *t*-test assumptions were examined. Table 4 summarizes the results of visually inspecting the Q-Q Plots in Appendix F and the results of the KS GOF test in Appendix G. The highlighted portions are those areas which did not satisfy the normal assumption.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Normal	yes	yes	yes	yes	yes	yes
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Normal	no	no	yes	no	yes	no

Table 4. FASCAM Normality

Next, the *F*-test was used to check for common variance between the Janus and JLink populations. The results of the F-tests are in Appendix H. Table 5 summarizes the

results of the tests for normality and common variance for each scenario. The highlighted portions are those populations which failed either the normality assumption or the common variance assumption, or both. The two sample *t*-test was only performed on those Janus/JLink pairs that met the normality assumption and passed the common variance test.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	yes		no		yes	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	no		no		no	

Table 5. FASCAM Satisfying Normality and Common Variance

Appendix I provides results of the pair-wise two sample *t*-tests, to include p-values and confidence intervals (CI), and highlights those pairs which reject the null hypothesis. Table 6 summarizes the FASCAM results. Note that both pairs tested failed to reject the null hypothesis.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		na		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		na		na	

Table 6. FASCAM Results of Two Sample *t*-Test

The Wilcoxon test was then applied to all pair-wise comparisons of FASCAM. Appendix J provides the results of the Wilcoxon test, and highlights those pairs which reject the null hypothesis. Tables 7 summarizes the FASCAM results and highlights those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		fail to rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		fail to rej null hyp	

Table 7. FASCAM Results of Wilcoxon Test

2. Chemical Kills

The chemical kills MOP was analyzed using the results in Table 8.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average	4.4	.3
	Variance	.49	.23
	Stand Dev	.70	.48
Armored HL	Average	12.3	2.5
	Variance	3.12	1.39
	Stand Dev	1.77	1.18
Armored Coalition SWA	Average	3.8	.1
	Variance	.4	.1
	Stand Dev	.63	.32
Armored Coalition HL	Average	12.3	2.9
	Variance	2.68	.99
	Stand Dev	1.64	.99
Light Infantry SWA	Average	9.9	.6
	Variance	10.1	1.6
	Stand Dev	3.18	1.26
Light Infantry HL	Average	69.6	36.6
	Variance	1.6	77.6
	Stand Dev	1.26	8.81

Table 8. Chemical Results

The analysis applied the two sample *t*-test to identify the specific scenarios which produced statistically different chemical kills between Janus and JLink. First, the assumptions were checked in the same manner as with FASCAM. Normality was determined based on the visual inspection of the Q-Q Plots and the results of the KS GOF test. Then, common variance was determined based on the results of the *F*-test. Table 9 summarizes the results of the tests for normality and common variance for each scenario. The highlighted portions are those populations which failed either the normality assumption or the common variance assumption, or both. Again, the two sample *t*-test was only performed on those Janus/JLink pairs that met the normality assumption and passed the common variance test.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	no		yes		no	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	no		no		no	

Table 9. Chemical Kills Satisfying Normality and Common Variance

The *t*-test results in Appendix I show that the one pair-wise comparison tested rejected the null hypothesis that the average number of chemical kills between Janus and JLink are statistically similar in scenario #1, HL. The result is summarized (for consistency) in Table 10.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		rej null hyp		na	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		na		na	

Table 10. Chemical Results of Two Sample *t*-Test

The Wilcoxon test was then applied to all pair-wise comparisons of chemical kills. Appendix J provides the results of the Wilcoxon test, and highlights those pairs which reject the null hypothesis. Tables 11 summarizes the chemical results and highlight those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	

Table 11. Chemical Results of Wilcoxon Test

3. Detection Range (Blue/Red)

The detection range MOP was analyzed using the results in Tables 12 and 13. As previously mentioned, the data for detection range was analyzed separately by blue and red force.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average	3.689	4.171
	Variance	.010	.005
	Stand Dev	.098	.072
Armored HL	Average	3.330	3.951
	Variance	.005	.012
	Stand Dev	.072	.107
Armored Coalition SWA	Average	3.619	4.073
	Variance	.033	.011
	Stand Dev	.181	.104
Armored Coalition HL	Average	3.362	3.948
	Variance	.009	.006
	Stand Dev	.096	.074
Light Infantry SWA	Average	2.067	2.075
	Variance	.002	.001
	Stand Dev	.040	.027
Light Infantry HL	Average	1.648	1.719
	Variance	.001	.001
	Stand Dev	.033	.036

Table 12. Blue Detection Range Results

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average Variance Stand Dev	2.470 .027 .165	3.389 .021 .146
Armored HL	Average Variance Stand Dev	2.000 .012 .108	2.882 .034 .183
Armored Coalition SWA	Average Variance Stand Dev	2.212 .011 .103	3.242 .027 .163
Armored Coalition HL	Average Variance Stand Dev	1.888 .007 .081	2.624 .054 .232
Light Infantry SWA	Average Variance Stand Dev	1.791 .001 .030	2.008 .001 .030
Light Infantry HL	Average Variance Stand Dev	1.559 .001 .027	1.672 .002 .041

Table 13. Red Detection Range Results

The ANOVA interaction plots in Appendix E for both blue and red detections show significant interaction between the scenario and the mode, illustrated by the larger gap in detection differences for scenarios 1 and 2 as compared to the detection difference for scenario 3. Such interaction is expected given that scenarios 1 and 2 used weapon systems with detection capability up to six kilometers, whereas scenario 3 used infantry units with detection capability of roughly two kilometers.

Testing for *t*-test assumptions showed that all detection populations satisfied the normality assumption and only the red detection range in scenario # 2, HL rejected the assumption of common variance. Tables 14 and 15 show the summarized results of the *t*-test for blue and red detection ranges, respectively.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		rej null hyp	

Table 14. Blue Detection Range Results of *t*-Test

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		rej null hyp		rej null hyp	

Table 15. Red Detection Range Results of *t*-Test

The Wilcoxon test was also applied to all pair-wise comparisons of detection ranges. Tables 16 and 17 summarize the results from Appendix J and highlight those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		rej null hyp	

Table 16. Blue Detection Range Results of Wilcoxon Test

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		rej null hyp	

Table 17. Red Detection Range Results of Wilcoxon Test

4. Kill Ranges (Blue/Red)

The kill range MOP was analyzed using the data in Tables 19 and 20. The data for kill ranges was analyzed separately by blue and red force.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average	2.074	2.394
	Variance	.123	.006
	Stand Dev	.350	.076
Armored HL	Average	1.955	2.556
	Variance	.045	.061
	Stand Dev	.212	.246
Armored Coalition SWA	Average	1.987	2.325
	Variance	.136	.216
	Stand Dev	.369	.465
Armored Coalition HL	Average	1.831	2.145
	Variance	.050	.120
	Stand Dev	.224	.346
Light Infantry SWA	Average	1.477	1.626
	Variance	.005	.001
	Stand Dev	.072	.027
Light Infantry HL	Average	1.301	1.375
	Variance	.003	.001
	Stand Dev	.055	.023

Table 18. Blue Kill Range Results

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average	2.847	3.100
	Variance	.033	.061
	Stand Dev	.181	.246
Armored HL	Average	2.607	3.00
	Variance	.016	.007
	Stand Dev	.127	.084
Armored Coalition SWA	Average	3.00	3.00
	Variance	.025	.065
	Stand Dev	.158	.255
Armored Coalition HL	Average	2.626	3.012
	Variance	.018	.009
	Stand Dev	.135	.095
Light Infantry SWA	Average	1.313	1.369
	Variance	.005	.004
	Stand Dev	.067	.067
Light Infantry HL	Average	1.317	1.455
	Variance	.004	.018
	Stand Dev	.067	.133

Table 19. Red Kill Range Results

The ANOVA interaction plots illustrate a significant interaction between the environment and the mode for red kill ranges. This interaction is interpreted as, not only are the mean

red kill ranges different between Janus and JLink, the differences are greater in HL terrain than SWA terrain.

Testing for *t*-test assumptions showed that all red kill range populations satisfied both the normality and common variance assumptions. Table 20 summarizes which scenarios satisfied the assumptions for blue kill ranges.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	no		yes		no	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	yes		no		no	

Table 20. Blue Kill Ranges Satisfying Normality and Common Variance

Tables 21 and 22 summarize the results from Appendix I of the two sample *t*-test for blue and red kill ranges, respectively.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		rej null hyp		na	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		na		na	

Table 21. Blue Kill Range Results of *t*-Test

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		fail to rej null hyp	

Table 22. Red Kill Range Results of *t*-Test

The Wilcoxon test was then applied to all pair-wise comparisons of kill ranges. Tables 23 and 24 summarize the results from Appendix J and highlight those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		rej null hyp	

Table 23. Blue Kill Range Results of Wilcoxon Test

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		fail to rej null hyp	

Table 24. Red Kill Range Results of Wilcoxon Test

5. Rounds Fired (Blue/Red)

The rounds fired MOP was analyzed using the data in Tables 25 and 26. The data for rounds fired was analyzed separately by blue and red force.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average Variance Stand Dev	85.3 1292.23 35.95	32.8 101.73 10.09
Armored HL	Average Variance Stand Dev	112.3 1360.01 36.88	58.1 40.32 6.35
Armored Coalition SWA	Average Variance Stand Dev	56.5 176.5 13.29	35.3 206.01 14.35
Armored Coalition HL	Average Variance Stand Dev	71.6 401.6 20.04	73.6 424.04 20.59
Light Infantry SWA	Average Variance Stand Dev	969.6 63081.38 251.16	621.3 1896.46 43.55
Light Infantry HL	Average Variance Stand Dev	1347.6 93197.38 305.28	1341.5 31205.83 176.65

Table 25. Blue Rounds Fired Results

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average Variance Stand Dev	110.1 1215.43 34.86	195.3 983.79 31.37
Armored HL	Average Variance Stand Dev	531.9 75729.21 275.19	323.8 6535.07 80.84
Armored Coalition SWA	Average Variance Stand Dev	144 6945.78 83.34	165.7 918.46 30.31
Armored Coalition HL	Average Variance Stand Dev	523.4 19137.16 138.34	411.9 18999.88 137.84
Light Infantry SWA	Average Variance Stand Dev	1626 11621.11 107.80	1619 4510 67.16
Light Infantry HL	Average Variance Stand Dev	1365.5 64852.5 254.66	1594 53604.44 231.53

Table 26. Red Rounds Fired Results

The results of the ANOVA test in Appendix E show that the average red rounds fired in JLink is statistically similar to the average red rounds fired in Janus, as evidenced by the p-value of .96 for Mode. Because of this result, no further statistical tests were conducted on the red rounds fired. Also, the results of the ANOVA interaction plots illustrate interaction between the environment and mode for blue rounds fired. The difference between Janus and JLink in the mean blue rounds fired in SWA is significantly larger than the mean blue rounds fired in HL.

Next, the two sample *t*-test was applied to all pairs of blue rounds fired. Results from testing for normality and common variance are summarized in Table 27.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	no		no		no	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Assumptions	yes		no		yes	

Table 27. Blue Rounds Fired Satisfying Normality and Common Variance

Table 28 summarizes the results from Appendix I of the two sample *t*-test for blue rounds fired.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	na		na		na	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		na		fail to rej null hyp	

Table 28. Blue Rounds Fired Results of *t*-Test

The Wilcoxon test was then applied to all pair-wise comparisons of blue rounds fired. Table 29 summarizes the results from Appendix J and highlights those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		fail to rej null hyp	

Table 29. Blue Rounds Fired Results of Wilcoxon Test

6. Loss Exchange Ratio (LER)

The LER MOP was analyzed using the results in Table 30.

	Summary Statistics	Janus Stand-Alone	JLink vs JLink
Armored SWA	Average Variance Stand Dev	2.182 .072 .269	1.161 .074 .273
Armored HL	Average Variance Stand Dev	1.659 .156 .395	1.505 .049 .221
Armored Coalition SWA	Average Variance Stand Dev	1.377 .025 .160	1.174 .070 .265
Armored Coalition HL	Average Variance Stand Dev	1.489 .040 .201	1.835 .122 .350
Light Infantry SWA	Average Variance Stand Dev	1.557 .254 .504	.937 .011 .104
Light Infantry HL	Average Variance Stand Dev	3.112 1.004 1.002	2.36 .436 .660

Table 30. LER Results

The analysis applied the two sample *t*-test to identify the specific scenarios which produced statistically different LERs between Janus and JLink. First, the *t*-test assumptions were checked in the same manner as before. The tests revealed that all

scenarios satisfied both the normality and common variance assumption except scenario #3, SWA. The results of the *t*-tests are summarized in Table 31.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		na		fail to rej null hyp	

Table 31. LER Results of Two Sample *t*-Test

The Wilcoxon test was then applied to all pair-wise comparisons of LERs. Tables 32 summarizes the LER test results and highlights those pairs which reject the null hypothesis that the two sample averages are statistically similar.

	Scenario #1, SWA		Scenario #1, HL		Scenario #2, SWA	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	rej null hyp		fail to rej null hyp		fail to rej null hyp	
	Scenario #2, HL		Scenario #3, SWA		Scenario #3, HL	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
Results	fail to rej null hyp		rej null hyp		fail to rej null hyp	

Table 32. LER Results of Wilcoxon Test

D. VARIABILITY WITHIN JLINK

The data in Appendix C are the results of 10 JLink runs, using the same scenarios and environments as described before, except that the same random number seed was

used for all runs. The reason for conducting these runs was to determine the variance within the JLink system and compare that variance to runs using different random number seeds. In essence, this test isolated the variance contributed by JLink alone.

Inspecting the variances in Appendix C, and comparing them to the variances of the runs using 10 different random number seeds in Appendix A, we see that the JLink variance using the same seed was generally slightly smaller than the variance in Appendix A. This finding indicates that most of the variability is generated within the runs, instead of from the changes in the random number seed.

V. ANALYSIS OF RESULTS

The results of the statistical tests from Chapter IV provide a firm basis for assessing the differences between the JLink system and its parent simulation, Janus. This chapter will analyze the results of the ANOVA test, two sample *t*-test, and Wilcoxon test and offer insights to the causes of these differences. Since the ANOVA test rejected the null hypothesis that the averages were statistically similar between Janus and JLink for all MOPs except red rounds fired, the analysis will focus primarily on where the differences occurred based on the results of the *t*-test and Wilcoxon test. The analysis includes possible causes for unexpected results and provides recommendations to resolve those issues derived from such results. The analysis of the results is presented by individual MOP.

A. FASCAM KILLS

The results from the two sample *t*-test and Wilcoxon test rejected the null hypothesis that the average FASCAM kills are the same between Janus stand-alone and JLink in only one instance, for scenario #2, HL. This would lead one to believe that JLink is accurately representing FASCAM under various conditions. Also, four out of six times Jlink produced average results which were within the accepted tolerance of $\Delta = 1$ kill. However, two issues must be addressed before drawing a final conclusion about JLink FASCAM: the location of the FASCAM minefield and the trend in the data between Janus and JLink.

As mentioned in Chapter III, paragraph C. 2, the player fires FASCAM from an artillery platform after the scenario begins. To remove aim-error variability due to human interaction, all runs were "pucked" to provide a common firing point between scenarios. Ballistic errors in azimuth and elevation are another source of location variability when firing from an artillery platform. Janus simulates these ballistic errors by drawing the x and y coordinates of the round's impact point from a normal distribution. So, in order to ensure that a FASCAM minefield is placed precisely in the same location in different runs, the runs must be "pucked" under almost identical conditions to ensure reasonable azimuth and elevation errors. The experiment satisfied the first condition, but due to JLink architecture and different random number generators, dispersion caused by the latter condition could not be completely controlled.

To reduce the dispersion of the minefields, FASCAM was fired in a relatively small geographic location, compared to the entire scenario. By firing five minefields per run, for 10 runs, in a relatively small location, one would expect the effect of minefield dispersion to be negligible over the entire experiment. However, after replaying some of the scenarios on the Janus Analyst Workstation and comparing the locations of the minefields between modes, it was evident that minefield dispersion would contribute to dissimilar FASCAM kills in Janus and JLink. Recall that blue forces fired FASCAM at specified red units traveling on a narrow route. Suppose that four of the five FASCAM minefields fired in Janus landed on the designated route whereas only three JLink minefields landed on the route, due to ballistic error. Under these circumstances, the experiment would not isolating the effects of the FASCAM minefields.

Another issue regarding the FASCAM results is the consistent trend towards greater FASCAM kills in Janus as compared to JLink. Such a trend forces the analyst to proceed with caution when drawing conclusions from the statistical tests. Although the tests indicate that the FASCAM results are statistically similar between modes (except in one instance), such a trend may indicate that the JLink FASCAM does not produce the same number of kills per mine as Janus FASCAM.

Given the results of the tests, the current configuration of JLink provides a fair representation of FASCAM as compared to Janus. Although there appears to be a trend in average FASCAM kills favoring Janus, the significance of the trend is diminished somewhat by the fact that one out of every six runs produced greater JLink FASCAM kills than Janus. The trend in average kills, however, does merit further investigation. Additional testing, isolating the effects of FASCAM, is necessary to determine if the JLink FASCAM is as lethal as Janus FASCAM.

B. CHEMICAL KILLS

In all cases, the *t*-test and the Wilcoxon test rejected the null hypothesis that the average chemical kills are the same between Janus stand-alone and JLink. Clearly, JLink's current configuration does not accurately replicate the effects of Janus chemical artillery.

In an attempt to identify the cause of the disparate test results and rectify the shortcoming, the JLink delivery method shown in Figure 2 was investigated. As aforementioned, Janus calculates artillery by volley as opposed to individual rounds, as dictated by the DIS standard. Calculating the artillery by volley results in a single large

chemical cloud which stays together for a much longer period of time as opposed to individual clouds which dissipate quickly and cover less area. Since the smaller clouds dissipate quickly, entities in contact are affected less by the smaller chemical clouds than by the larger aggregated cloud.

In order to correct this shortcoming, the World Modeler software was rewritten so that whenever a user participates in a JLink to JLink game, all chemical artillery will be fired and portrayed by volley as opposed to individual rounds. After making the corrections in the code, 10 additional runs were performed using the SWA armored scenario. The results of the scenario were more in line with what was originally expected.

The ten runs of both Janus and JLink yielded an average of 10.3 and 10.5 chemical kills respectively (Table 33). Because the data satisfied the assumptions of normality and common variance with a Q-Q Plot and *F*-test respectively, a two-sample *t*-test was also conducted. Since the generated test statistic 0.7356 is less than the critical value of 2.101, the conclusion is that the means do not differ significantly.

	Chemical Kills	
RUN #	Janus	JLink
1	9	9
2	11	11
3	12	11
4	9	11
5	9	11
6	11	12
7	11	10
8	8	11
9	11	8
10	12	11
XBAR	10.3	10.5
VAR	2.011	1.389
STDE	1.418	1.179

Table 33. Chemical Kills for Volley Fire

These results support the finding that JLink accurately represents chemical artillery in a SWA armored scenario. Additional testing using other scenarios is necessary to conclude that JLink accurately portrays chemical artillery under varied conditions. The results show that chemical rounds must be fired in volleys, as opposed to individual rounds, whenever a user plays a JLink to JLink game. Software upgrades will include a toggle transparent to the user so that JLink automatically sends out volleys as opposed to individual rounds whenever a user indicates that the other participating DIS simulation is another JLink.

C. DETECTION RANGES (BLUE/RED)

The next MOP analyzed was detection range, analyzed separately by blue force and red force, using the data from Appendix B. (The headings "Det Ranges Blue/Red" in Appendix B refer to the those units doing the detecting). As mentioned previously, separating the detection ranges by side offers a clearer interpretation of the results and additional information to whether JLink is accurately simulating units performing a specific type of mission, in this case attacking and defending.

The two-sample *t*-test and the Wilcoxon test rejected the null hypothesis that the average blue and red detection ranges are similar for every scenario except for the blue detection ranges in scenario #3, SWA.

Next, the thesis compared the accepted $\Delta = 0.3$ kilometer tolerance for detection ranges in scenarios 1 and 2, and $\Delta = 0.1$ kilometers for scenario 3, to the confidence intervals from Appendix I, to determine if any detection ranges were within acceptable tolerance. The comparison concluded that none of the detection ranges were within the

acceptable tolerance, with the one exception noted above. (Figure 7 illustrates the method for applying the Δ value to the confidence interval for scenario #3, HL, blue detection range). Additionally, a consistent trend in the detection data surfaced; the JLink detection ranges were always larger than the Janus detection ranges, for both the blue and red forces.

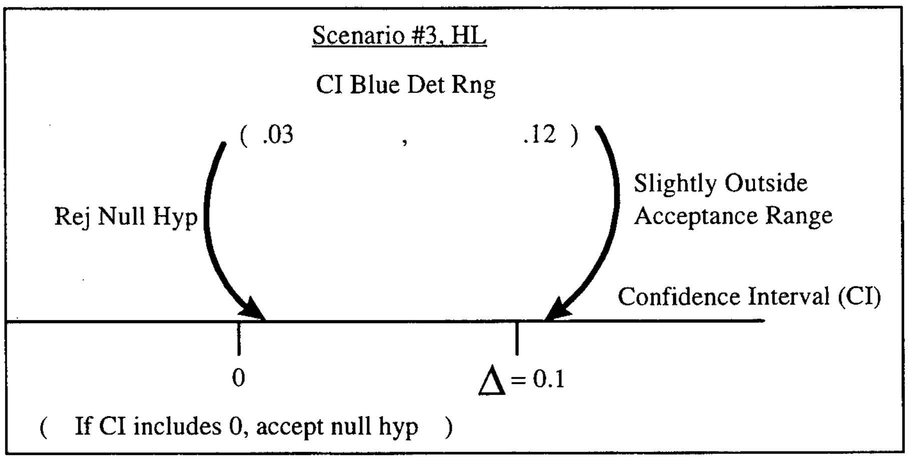


Figure 7. Confidence Intervals Versus Acceptance Range

The next step was to identify the cause of the disparate results and the trend in the data. The first issue investigated was the passing of the entity's z-coordinate. If the entity's z-coordinate is not passed properly to JLink, or interpreted properly by JLink, the entity could be simulated above ground level, resulting in better line of sight and extended detection ranges. This hypothesis turned out to be incorrect, however, because JLink can determine which entities are ground entities. When the information about a ground entity is passed to JLink, JLink assigns the entity the x and y coordinates passed from Janus and places the entity on the ground. The ground entity then uses the ground z-coordinate to perform line of sight calculations.

The second proposed solution focused on the fact that something in the battlefield environment was affecting the detection ranges. The issue of artillery delivered smoke and munitions was suggested as a possible cause. All scenarios used large volumes of artillery smoke and artillery High Explosive (HE) rounds. As discussed in the analysis of chemical kills, Janus and JLink simulated artillery delivery methods differently in this experiment. If the dimension of the chemical cloud could affect the number of chemical kills, then the dimensions of any cloud generated from an artillery munition may also affect the range at which an entity can detect through the cloud.

To test the proposed solution, the SWA armored scenario was re-run, excluding all artillery from both sides. Thus, in this case there were no clouds resulting from artillery smoke or HE rounds on the battlefield. The hypothesis was that the artillery simulated as a volley (Janus) led to decreased visibility, and shorter detection ranges, than artillery simulated as individual rounds (JLink). The scenario was then run 10 times in both the Janus and JLINK modes, using the same random number seeds. The results yielded an average detection range for red Janus entities of 2.532 kilometers, while the average detection range for the red JLINK entities was 2.463 kilometers. The average detection range for blue Janus entities was 3.885 versus 3.767 for the blue JLINK entities. Table 34 depicts the actual ranges for each run. The assumption of normality was satisfied, but the F-Test concluded that the variances for the populations were not the same for the blue Janus and blue JLink detection ranges. The variances were the same, however, for the red Janus and red JLink detection ranges. Finally, a two-sample t-test showed that in both cases, the means for the populations were not significantly different. This analysis provides a basis for concluding that the different artillery delivery methods

contributed to the disparate detection results. Further, this thesis concludes that the volley method used by Janus to deliver artillery munitions generates shorter detection ranges than the individual round method due to the dimensions and dissipation rate of the cloud.

Currently, the software has not been rewritten in JLink to fire artillery using the same method as Janus. After the code is rewritten, several additional experiments will be done to ensure that the artillery is being accurately played using the volley method, and that this method generates similar detection ranges between Janus and JLink.

	Det Ranges Blue		Det Ranges Red	
RUN #	Janus	JLink	Janus	JLink
1	3.863	3.785	2.294	2.711
2	3.940	3.753	2.513	2.386
3	3.846	3.846	2.541	2.541
4	3.778	3.877	2.408	2.719
5	3.918	3.918	2.890	2.889
6	4.017	3.616	2.912	2.166
7	3.863	3.567	2.294	2.319
8	3.912	4.021	2.715	2.512
9	3.856	3.660	2.377	2.275
10	3.853	3.631	2.377	2.119
XBAR	3.885	3.767	2.532	2.464
VAR	0.004	0.022	0.054	0.065
STDEV	0.065	0.149	0.232	0.255
t-Test Stat	0.040		.515	
Crit. Value	2.101		2.101	

Table 34. Detection Ranges Without Artillery

D. KILL RANGES (BLUE/RED)

The next MOP analyzed was kill range, analyzed separately by blue force and red force, using the data from Appendix B. (The headings "Kill Ranges Blue/Red" in Appendix B refer to the those units being killed). The results of the two-sample *t*-test and

the Wilcoxon test rejected the null hypothesis that the average kill ranges (blue and red) are same between modes in six instances :

1. Blue Kill Ranges in Scenario #1, SWA
2. Blue Kill Ranges in Scenario #1, HL
3. Red Kill Ranges in Scenario #1, HL
4. Red Kill Ranges in Scenario #2, HL
5. Blue Kill Ranges in Scenario #3, SWA
6. Blue Kill Ranges in Scenario #3, HL

Next, the acceptable tolerance range of $\Delta = 0.2$ kilometers for scenarios 1 and 2, and $\Delta = 0.05$ kilometers for scenario 3, was compared to the kill range CIs in Appendix I for those scenarios which rejected the null hypothesis. The results of the comparison were that none of the CIs fell within the acceptable tolerance. This finding can be interpreted by stating that the mean kill ranges in Janus and JLink in these scenarios are not the same, and indeed so dissimilar that the difference in the means falls outside the acceptable tolerance.

As with the detection ranges data, a consistent trend occurred in the kill range data; the kill ranges for JLink were consistently greater than the kill ranges for Janus. This result is not surprising in light of the similar trend in detection ranges. There is a strong likelihood that if an entity can detect at further range, then it can acquire and target at greater distances, and subsequently kill at longer ranges. This reasoning is based on the method by which a Janus entity performs the engagement sequence. After conducting a line of sight calculation, Janus determines the target's location and identity. Once identified, Janus determines the target's priority and places it on the target list. The target

list for each Janus entity determines which targets will be engaged and in what order. Janus then acquires the target and engages. The engagements may, or may not, lead to a kill. This entire sequence, however, stems from the initial detection. Therefore, if the detection ranges are statistically similar, then the engagement sequences in both Janus and JLink may be in agreement.

The link between detection ranges and kill ranges focused the investigation into resolving the disparate kill range issue. As mentioned in the previous section, further analysis of the detection ranges, without firing artillery, has begun using the armored scenario in SWA. This ongoing investigation will also analyze the kill ranges to verify whether the kill ranges were indeed affected by the detection ranges. The assumption is that if the detection range issue is resolved, the kill ranges between Janus and JLink will become more similar. Presently, this hypothesis is being tested.

The last result analyzed for kill ranges is the evidence of interaction between the environment and mode for mean red kill ranges. The interaction plot in Appendix E shows that the red force has the advantage in JLink of greater kill ranges, but the advantage is even more pronounced when fighting in HL terrain as compared to SWA terrain. The assumption that greater detection ranges in JLink lead to greater kill ranges in JLink accounts for part of the overall advantage. However, all other factors being equal, one would expect the JLink kill range advantage to be consistent between scenarios since the JLink detection range advantage is consistent between scenarios. Because there is a larger red kill range difference in the HL as compared to SWA, further investigation is needed to identify the factor causing the difference.

One likely factor causing the difference in red kill ranges between environments and mode is the different terrain features of HL and SWA. Terrain features affect line of sight, which then affect detections, and subsequently the entire engagement process leading to rounds fired. Further testing should focus on this factor by simulating battalion size forces attacking under these two different environments. The issue of detection ranges should be resolved first, however, in order to isolate the factors causing differences in kill ranges.

Overall, JLink's current configuration returns kill ranges which are statistically similar to those in Janus in six of 12 cases. These results indicate that JLink provides a setting which generally replicates the kill ranges of different types of units fighting in different environments. In particular, JLink appears quite accurate in producing comparable kill ranges for armored coalition scenarios fighting on the SWA terrain, and attacking light infantry forces fighting on both HL and SWA terrain. These results also indicate that the JLink battlefield produces fairly accurate kill ranges for units conducting different types of missions, in this case an attacking red force against a defending blue force. Once further testing is complete, and the issue of detection range is resolved, one would expect JLink to produce kill ranges even closer to those of Janus.

E. ROUNDS FIRED (BLUE/RED)

The next MOP analyzed was rounds fired, analyzed separately by blue force and red force, using the data from Appendix B. The ANOVA returned a p-value of .96 for red rounds fired, which indicates that JLink is providing a battlefield setting which

replicates the average number of rounds fired comparable to Janus for a battalion-size armored or infantry force in the offense, under different environmental conditions.

The results of the two-sample *t*-test and the Wilcoxon test for blue rounds fired were mutually supporting, although the *t*-test was not performed on several data sets because they did not satisfy *t*-test assumptions, primarily due to wide differences in variance between populations. The tests rejected the null hypothesis that the average blue rounds fired are the same between modes in four instances :

1. Blue Rounds Fired in Scenario #1, SWA
2. Blue Rounds Fired in Scenario #1, HL
3. Blue Rounds Fired in Scenario #2, SWA
4. Blue Rounds Fired in Scenario #3, SWA

The ANOVA supports these findings as indicated by the *F*-values for Mode in Appendix E. The *F*-value of 11.929 for the blue rounds fired is interpreted as, the average blue rounds fired among all Janus scenarios are statistically different than the average blue rounds fired among all JLink scenarios.

The interaction between environment and mode for blue rounds fired indicates that the difference in blue rounds fired between Janus and JLink is even greater when placed in the SWA environment. As mentioned previously, investigation into the cause of this interaction must focus on the competing terrain of HL and SWA. Terrain affects line of sight and ultimately the engagement sequence and rounds fired. Once the detection range issue is resolved, further testing should focus on simulating units in the defense under different environments.

Next, the four scenarios which rejected the null hypothesis were analyzed to determine if the differences in the number of rounds fired between Janus and JLink satisfied the accepted tolerance. Recall that the accepted tolerance for rounds fired was $\Delta = 10\%$ of the total Janus rounds fired. Applying the method illustrated in Figure 7 of comparing the MOP's confidence interval to the determined Δ - value resulted in none of the four being within acceptable tolerance.

Based on the results of the statistical tests for rounds fired, JLink provides an accurate replication of the battlefield that generates an average number of rounds fired comparable to Janus for a battalion-size unit attacking under different environmental conditions. JLink also provides a fare replication of the battlefield that generates similar average rounds fired for a company-size unit defending in HL terrain.

Further, in reference to the discussion of the engagement process in paragraph D above, the number of rounds fired could become more similar between Janus and Jlink once the detection range and kill range issues are resolved. Since JLink consistently had greater detection ranges and kill ranges than Janus in this experiment, one would conclude that the number of rounds fired were affected by the disparity given that all three MOPs are linked in the engagement process. The ongoing experiment of the armored scenario in SWA, stripped of all artillery munitions, will be a valuable study to analyze the effect that accurate detection ranges have on rounds fired, especially since both the blue and red forces in the armored scenario in SWA appeared to have different averages of numbers of rounds fired.

F. LOSS EXCHANGE RATIO (LER)

The LER is the ratio of red casualties to blue casualties, and offers a quantitative method to assess the overall outcome of a battle. Given that the factors affecting the ratio are accurately portrayed, LERs determined to be statistically similar provide strong supporting evidence that JLink is accurately portraying the entire scenario. In this case, both the *t*-test and Wilcoxon test failed to reject the null hypothesis in four of the six scenarios when testing the LERs. This indicates that the Janus and JLink LERs for these four scenarios are similar. In scenario #1, SWA and scenario #3, SWA, the hypothesis of equal LERs was rejected. Although, on four of six occasions, the null hypothesis was not rejected, an analyst must be cautious to accept the conclusion that JLink is accurately portraying the overall battle under these four conditions based on these results.

The question posed then is, why are two of the six not statistically similar? The LER is a function of several other factors, primarily kills and detections. Previous analysis has shown that kills due to chemical artillery were not accurately portrayed by JLink during the experiment. Chemical kills is a factor of the LER, and inaccuracies with simulating those kills will adversely affect the LER for that scenario. Additionally, discussion of the detection ranges concluded that JLink did not satisfactorily replicate the detection ranges in this experiment, which is the another major contributing factor of the LER. The chemical kills and detection range issues alone could lead to dissimilar LERs between Janus and JLink.

Given that at least two inputs to the LER equation may not have been accurate, it is reassuring that four of the six combinations were within statistical tolerance. There is a

strong likelihood that once the artillery delivery methods in JLink are identical to Janus, the ongoing investigations into chemical kills and detection ranges may be resolved. After these issues are resolved, this MOP should be analyzed again. One would expect the LERs to become more similar for all scenarios once these major factors in the LER equation are corrected.

VI. CONCLUSIONS AND RECOMMENDATIONS

This chapter draws conclusions from Chapter V, assessing the current state of JLink in terms of varied scenarios, coalition warfare, and specific combat functions. The chapter also provides recommendations for further study of JLink issues presented in this thesis.

A. CONCLUSIONS

1. Varied Scenarios

Chapter II describes varied scenarios as different types of combat units in the offense and defense, negotiating obstacles, under different environmental conditions. Such scenarios had yet to be tested in JLink to the extent tested in this thesis. To assess whether JLink replicates these scenarios in a way similar to Janus, the MOPs detection range, kill range, rounds fired, and LER were analyzed. The first three MOPs allowed for analysis of the basic procedures of an engagement, which is critical to arriving at valid conclusions about scenario fidelity. The LER offered a quantitative method to assess the overall scenario.

Although JLink did not accurately replicate detection ranges in this experiment, the related MOPs of kill range and rounds fired fared well in the overall analysis. Also, statistical tests concluded that four of the six JLink LERs were statistically similar to the corresponding Janus LERs. These results support the conclusion that JLink is robust enough to sufficiently replicate varied scenarios in a manner similar to Janus, despite inaccurate inputs in detection ranges.

2. Coalition Warfare

The same MOPs used for drawing conclusions about varied scenarios were used to assess JLink's ability to portray coalition warfare. Notwithstanding the detection range inaccuracies, all MOPs analyzed for scenario #2, armored coalition in both HL and SWA environments, failed to reject the null hypothesis, except for red kill ranges in HL and blue rounds fired in SWA. Given these results, the thesis concludes that JLink produces similar results to stand-alone Janus when simulating coalition warfare.

3. Specific Combat Functions

a. FASCAM

The MOP used to assess JLink FASCAM fidelity was the number of kills resulting from FASCAM minefields. Although the statistical results for FASCAM rejected the null hypothesis only once, the trend towards consistently higher Janus FASCAM kills indicates that Janus FASCAM may be more lethal than JLink FASCAM. Despite the trend, however, JLink appears to provide a fair representation of FASCAM. A stronger conclusion must be borne out of additional FASCAM testing which isolates the minefield.

b. Chemical Artillery

The MOP used to assess JLink chemical artillery was the number of kills

generated by chemical artillery rounds. In all cases, the statistical tests rejected the null hypothesis that the average number of Janus chemical kills were the same as the average number of JLink chemical kills. Given these results, the thesis concludes that JLink's configuration during the experiment did not accurately replicate the effects of Janus chemical artillery.

The investigation into the cause of the disparate chemical data resulted in a solution which changed the delivery of JLink chemical artillery from an individual round method to a volley method. Changing to the volley method and rerunning the armored scenario in SWA produced very similar chemical kills between Janus and JLink. The conclusion is that JLink replicates the effects of Janus chemical artillery for an armored scenario in SWA terrain when fired in volley. Further, the volley method must be used whenever a user simulates a JLink to JLink battle.

B. RECOMMENDATIONS

1. Artillery Code Upgrade

After investigating the cause of the detection range disparities, a brief study was conducted without artillery to support the hypothesis that different artillery delivery methods contributed to the different detection results. The study, which involved the armored scenario in SWA, proved conclusive. Without artillery, the detection ranges were statistically similar. The conclusion is that different artillery delivery methods produce different detection ranges.

The recommendation is that JLink follow the volley method used in Janus

stand-alone, and that code be rewritten in JLink to fire artillery using the volley method when two JLink players are involved in a simulation.

2. Further Testing of Detection Ranges, Kill Ranges, Rnds Fired, LERs

Once the JLink code is rewritten using the volley method for artillery, further tests are necessary using various scenarios and environments to confirm that JLink scenarios are generating similar detection ranges as compared to Janus scenarios.

Also, the kill ranges for these scenarios should be analyzed to ensure JLink scenarios are producing similar kill ranges and LERs as compared to Janus. The assumption is that detection ranges significantly affect kill ranges, based on the discussion of the engagement sequence. Once the detection issue is resolved, one would expect the kill ranges to be more aligned between Janus and JLink. Then, further testing should focus on the kill range results of a battalion-size unit attacking in the HL and SWA terrain in order to identify the source of interaction between environment and mode.

Rounds fired should also be analyzed in the re-run scenarios. Again, given the engagement sequence, one would expect the average rounds fired to be more similar between Janus and JLink once detection ranges and kill ranges are corrected. Additional testing should focus on units in the defense under both environments to isolate the cause of environment and mode interaction for blue rounds fired.

Since detection ranges, kill ranges, and rounds fired are inputs into the LER equation, one would expect the JLink LERs to be more in line with the Janus LERs once the detection ranges and kill ranges generate similar results between the two modes.

Testing and resolving these issues will lead to a more robust JLink system, capable of accurately portraying more diverse scenarios.

3. Further Testing of FASCAM and Chemical Artillery

The trend in the data consistently showing greater Janus FASCAM kills requires that FASCAM be investigated further. Also, chemical artillery must be tested using scenarios other than the previously tested armored scenario in SWA to confirm that the JLink code upgrades for chemical rounds sufficiently replicates chemical kills between the two modes. Improvements in both FASCAM and chemical artillery will diversify JLink and increase its value as a training and analytical tool.

C. FINAL COMMENTS

This thesis provides the latest assessment of JLink fidelity. The conclusions and recommendations of this thesis will improve distributed interoperability. However, in order to achieve the final goal of 100% interoperability between JLink systems, continued testing is necessary on the topics mentioned in this thesis and future topics generated by the evolving Jlink system.

APPENDIX A. RAW DATA

SCENARIO #1, SWA RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	4	4	4	0	1.95	1.08	3.400	3.844	2.411	2.636	236	248
2	2	2	6	0	2.11	0.81	3.351	3.814	2.493	2.638	119	235
3	0	1	5	0	2.59	0.96	3.278	3.862	2.632	2.673	247	201
4	6	0	4	0	2.14	0.96	3.294	3.905	2.749	2.876	183	163
5	2	3	4	0	2.47	1.09	3.298	3.826	2.464	2.671	255	191
6	1	2	4	1	1.95	1.19	3.394	3.813	2.668	2.641	150	302
7	3	2	4	0	2	1	3.260	3.885	2.391	2.634	225	228
8	3	3	4	1	2.61	1.41	3.232	3.753	2.739	3.057	205	223
9	3	1	5	1	2.05	1.39	3.338	3.765	2.561	2.746	187	246
10	3	2	4	0	1.95	1.72	3.425	3.647	2.650	2.830	147	244
XBAR	2.7	2	4.4	0.3	2.182	1.161	3.327	3.811	2.576	2.740	195.4	228.1
VAR	2.68	1.33	0.49	0.23	0.072	0.074	0.004	0.006	0.017	0.020	2144.04	1428.1
STDEV	1.64	1.15	0.70	0.48	0.269	0.273	0.065	0.075	0.131	0.141	46.30	37.79

SCENARIO #1, HL RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	4	3	8	3	2.09	1.69	3.027	3.544	2.406	2.983	546	328
2	3	1	12	4	1.46	1.52	3.099	3.772	2.388	2.711	267	256
3	6	2	13	2	1.36	1.8	3.089	3.733	2.428	2.878	454	370
4	3	1	13	4	1.29	1.43	2.889	3.581	2.342	2.946	815	551
5	1	2	14	1	1.95	1.32	2.945	3.601	2.311	2.905	570	393
6	0	1	13	4	1.56	1.87	2.843	3.455	2.179	2.687	418	354
7	2	0	11	2	1.37	1.19	2.913	3.680	2.347	2.665	705	410
8	2	1	13	2	1.6	1.52	2.914	3.305	2.085	2.832	669	453
9	4	2	14	2	2.5	1.32	2.853	3.699	2.532	2.663	839	320
10	4	2	12	1	1.41	1.39	2.743	3.552	2.346	2.858	1159	384
XBAR	2.9	1.5	12.3	2.5	1.659	1.505	2.931	3.592	2.337	2.813	644.2	381.9
VAR	2.99	0.72	3.12	1.39	0.156	0.049	0.013	0.020	0.016	0.015	64580.18	6452.77
STDEV	1.73	0.85	1.77	1.18	0.395	0.221	0.112	0.140	0.126	0.121	254.13	80.33

SCENARIO #2, SWA RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	2	3	4	0	1.26	1.4	3.196	3.364	2.574	2.635	141	147
2	1	0	3	0	1.13	0.75	3.230	3.415	2.360	2.640	136	245
3	4	1	5	0	1.52	1.17	3.069	3.511	2.746	2.528	215	189
4	4	2	4	1	1.67	1.21	2.955	3.263	2.447	2.563	140	231
5	2	3	3	0	1.38	1.65	3.018	3.379	2.761	2.735	151	227
6	4	1	3	0	1.48	1.05	3.149	3.234	2.499	2.521	387	152
7	4	0	4	0	1.48	1.22	3.086	3.297	2.462	2.527	182	228
8	2	3	4	0	1.29	1.33	3.157	3.395	2.358	2.484	150	184
9	0	2	4	0	1.26	1.15	3.217	3.366	2.553	2.960	304	180
10	0	0	4	0	1.3	0.81	3.135	3.200	2.469	3.262	199	227
XBAR	2.3	1.5	3.8	0.1	1.377	1.174	3.121	3.342	2.523	2.685	200.5	201
VAR	2.68	1.61	0.4	0.1	0.025	0.070	0.008	0.009	0.020	0.061	6934.5	1234.22
STDEV	1.64	1.27	0.63	0.32	0.160	0.265	0.089	0.094	0.140	0.247	83.27	35.13

SCENARIO #2, HL RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	1	0	11	2	1.3	2.4	2.106	2.398	2.247	2.745	385	353
2	4	1	12	3	1.07	1.64	2.054	2.594	2.414	2.715	516	362
3	2	1	9	2	1.48	2.1	2.115	2.370	2.294	2.677	607	452
4	6	0	14	2	1.58	2	2.105	2.515	2.281	2.639	448	312
5	2	0	14	5	1.78	1.67	2.150	2.519	2.463	2.825	478	520
6	2	1	14	2	1.46	1.92	2.085	2.496	2.182	2.688	591	711
7	2	1	12	3	1.71	1.5	2.084	2.322	2.167	2.881	795	344
8	2	0	13	4	1.5	1.18	2.081	2.400	2.115	2.778	813	688
9	4	1	13	3	1.44	2.1	2.140	2.401	2.164	2.609	711	522
10	1	1	11	3	1.57	1.84	2.105	2.572	2.489	2.522	604	591
XBAR	2.6	0.6	12.3	2.9	1.489	1.835	2.103	2.459	2.282	2.708	594.8	485.5
VAR	2.49	0.27	2.68	0.99	0.040	0.122	0.001	0.008	0.018	0.011	20762.18	21062.72
STDEV	1.58	0.52	1.64	0.99	0.201	0.350	0.028	0.092	0.133	0.106	144.09	145.13

SCENARIO #3, SWA RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	2	0	9	0	1.28	0.94	1.935	2.036	1.334	1.526	2640	2396
2	0	2	15	0	1.36	0.88	1.932	2.028	1.437	1.528	2486	2253
3	0	0	12	0	1.53	0.79	1.956	2.050	1.378	1.493	2417	2202
4	1	0	6	0	2.28	0.95	1.895	2.060	1.309	1.531	2890	2309
5	0	0	9	3	1.92	1.06	1.937	2.011	1.312	1.449	2712	2163
6	0	0	12	3	1.39	0.77	1.964	2.055	1.361	1.560	2553	2111
7	5	0	12	0	2.47	0.95	1.906	2.026	1.408	1.468	2981	2292
8	0	0	6	0	1.17	0.92	1.931	2.050	1.436	1.492	2339	2156
9	2	0	6	0	0.92	1.03	1.963	2.057	1.441	1.484	2288	2207
10	1	0	12	0	1.25	1.08	1.988	2.032	1.371	1.485	2650	2314
XBAR	1.1	0.2	9.9	0.6	1.557	0.937	1.941	2.041	1.379	1.501	2595.6	2240.3
VAR	2.54	0.4	10.1	1.6	0.254	0.011	0.001	0.000	0.003	0.001	51096.71	7733.79
STDEV	1.60	0.63	3.18	1.26	0.504	0.104	0.028	0.016	0.051	0.034	226.05	87.94

SCENARIO #3, HL RESULTS

	FASCAM Kills		Chem Kills		LER		Detection Ranges		Kill Ranges		Rounds Fired	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	2	1	69	33	5.63	2.22	1.588	1.713	1.323	1.443	2815	2896
2	0	1	69	33	2.71	2.48	1.610	1.686	1.294	1.396	2383	2713
3	0	1	69	48	2.72	2.49	1.630	1.677	1.303	1.374	2895	3310
4	1	0	69	42	3.74	3.65	1.649	1.658	1.328	1.306	3308	2921
5	2	1	72	33	3.51	2.06	1.579	1.716	1.228	1.495	2412	3121
6	0	1	69	21	2.18	2.6	1.665	1.667	1.372	1.369	2786	2823
7	0	0	72	36	2.59	1.32	1.590	1.770	1.382	1.511	2284	2978
8	1	1	69	30	2.42	2.35	1.605	1.725	1.250	1.416	2816	3246
9	3	0	69	39	2.93	2.9	1.589	1.664	1.376	1.345	2727	2565
10	1	0	69	51	2.69	1.53	1.593	1.733	1.271	1.567	2705	2782
XBAR	1	0.6	69.6	36.6	3.112	2.36	1.610	1.701	1.313	1.422	2713.1	2935.5
VAR	1.11	0.27	1.6	77.6	1.004	0.436	0.001	0.001	0.003	0.007	88588.1	55293.61
STDEV	1.05	0.52	1.26	8.81	1.002	0.660	0.029	0.037	0.054	0.082	297.64	235.15

APPENDIX B. RAW DATA SEPARATED BY SIDE

SCENARIO #1, SWA RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	3.847	4.231	2.381	3.398	1.986	2.356	2.704	2.987	60	27	176	221
2	3.707	4.139	2.344	3.393	1.903	2.413	2.805	3.028	54	23	65	212
3	3.616	4.220	2.412	3.510	1.952	2.343	2.901	3.064	172	29	75	172
4	3.656	4.274	2.480	3.425	2.020	2.393	3.153	3.404	87	29	96	134
5	3.570	4.164	2.661	3.452	1.862	2.559	2.725	2.826	102	23	153	168
6	3.825	4.068	2.308	3.538	1.905	2.353	3.083	2.930	63	55	87	247
7	3.570	4.245	2.593	3.502	1.929	2.381	2.661	2.909	108	30	117	198
8	3.651	4.187	2.308	3.108	3.049	2.458	2.613	3.630	85	30	120	193
9	3.764	4.087	2.414	3.418	2.039	2.404	2.860	3.037	64	38	123	208
10	3.684	4.094	2.800	3.148	2.096	2.276	2.968	3.185	58	44	89	200
XBAR	3.689	4.171	2.470	3.389	2.074	2.394	2.847	3.100	85.3	32.8	110.1	195.3
VAR	0.010	0.005	0.027	0.021	0.123	0.006	0.033	0.061	1292.23	101.73	1215.43	983.79
STDEV	0.098	0.072	0.165	0.146	0.350	0.076	0.181	0.246	35.95	10.09	34.86	31.37

SCENARIO #1, HL RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	3.389	3.845	2.022	2.959	2.000	2.790	2.629	3.112	171	65	375	263
2	3.419	4.047	2.076	3.078	1.821	2.302	2.835	3.003	87	59	180	197
3	3.419	4.060	2.068	3.092	2.249	2.580	2.590	3.060	150	65	304	305
4	3.259	3.970	2.142	2.886	2.138	3.019	2.534	2.889	78	59	737	492
5	3.362	3.901	1.880	3.086	1.920	2.689	2.534	3.078	149	60	421	333
6	3.211	3.913	2.070	2.530	1.726	2.293	2.470	2.908	147	62	271	292
7	3.258	4.060	2.103	2.797	1.851	2.427	2.740	2.866	86	49	619	361
8	3.349	3.765	1.892	2.686	1.617	2.601	2.410	3.000	87	62	582	391
9	3.338	4.071	1.849	2.835	2.248	2.237	2.664	3.014	90	53	749	267
10	3.296	3.873	1.903	2.871	1.978	2.623	2.670	3.045	78	47	1081	337
XBAR	3.330	3.951	2.000	2.882	1.955	2.556	2.607	2.997	112.3	58.1	531.9	323.8
VAR	0.005	0.012	0.012	0.034	0.045	0.061	0.016	0.007	1360.01	40.32	75729.21	6535.07
STDEV	0.072	0.107	0.108	0.183	0.212	0.246	0.127	0.084	36.88	6.35	275.19	80.84

SCENARIO #2, SWA RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	3.841	4.128	2.316	3.271	1.871	2.098	3.277	3.115	59	35	82	112
2	3.718	4.118	2.218	3.365	1.788	2.205	3.019	3.026	34	74	102	171
3	3.685	3.992	2.292	3.325	2.687	2.098	2.796	2.958	42	29	173	160
4	3.614	4.075	2.219	3.166	1.742	2.197	2.993	2.902	49	32	91	199
5	3.584	4.151	2.115	3.376	2.672	2.179	2.840	3.162	72	38	79	189
6	3.173	4.090	2.030	2.998	1.766	2.246	3.173	2.838	52	28	335	124
7	3.784	4.103	2.328	3.219	1.864	2.121	2.929	2.901	74	36	108	192
8	3.611	4.090	2.091	3.234	1.771	2.110	2.900	2.843	62	30	88	154
9	3.558	4.176	2.208	3.492	1.790	2.375	3.179	3.609	70	22	234	158
10	3.625	3.812	2.302	2.977	1.916	3.626	2.940	2.684	51	29	148	198
XBAR	3.619	4.073	2.212	3.242	1.987	2.325	3.005	3.004	56.5	35.3	144	165.7
VAR	0.033	0.011	0.011	0.027	0.136	0.216	0.025	0.065	176.5	206.01	6945.78	918.46
STDEV	0.181	0.104	0.103	0.163	0.369	0.465	0.158	0.255	13.29	14.35	83.34	30.31

SCENARIO #2, HL RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	3.312	3.900	1.944	2.913	2.033	1.738	2.423	3.164	78	91	307	262
2	3.573	4.036	1.907	3.021	2.073	2.226	2.797	3.028	41	60	475	302
3	3.361	3.991	1.792	2.577	2.011	1.741	2.500	3.145	64	59	543	393
4	3.301	3.982	1.866	2.648	1.683	2.066	2.737	2.932	83	67	367	245
5	3.465	3.904	1.899	2.709	1.984	2.599	2.769	2.963	56	81	422	439
6	3.245	3.890	2.025	2.496	1.718	2.275	2.541	2.908	67	123	524	588
7	3.401	4.074	1.807	2.474	1.536	2.544	2.599	3.112	66	56	729	288
8	3.338	3.970	1.839	2.717	1.612	2.561	2.492	2.967	116	58	697	630
9	3.335	3.838	1.993	2.227	1.582	1.887	2.633	2.970	63	72	648	450
10	3.286	3.895	1.806	2.463	2.083	1.809	2.765	2.927	82	69	522	522
XBAR	3.362	3.948	1.888	2.624	1.831	2.145	2.626	3.012	71.6	73.6	523.4	411.9
VAR	0.009	0.006	0.007	0.054	0.050	0.120	0.018	0.009	401.6	424.04	19137.16	18999.88
STDEV	0.096	0.074	0.081	0.232	0.224	0.346	0.135	0.095	20.04	20.59	138.34	137.84

SCENARIO #3, SWA RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	2.050	2.038	1.811	2.034	1.359	1.616	1.313	1.427	875	646	1765	1750
2	2.071	2.070	1.793	1.990	1.481	1.611	1.405	1.433	866	628	1620	1625
3	2.057	2.116	1.821	1.992	1.596	1.594	1.235	1.365	972	557	1445	1645
4	2.014	2.068	1.747	2.052	1.372	1.683	1.282	1.370	1295	654	1595	1655
5	2.046	2.034	1.778	1.989	1.450	1.635	1.240	1.271	1137	638	1575	1525
6	2.087	2.107	1.833	2.007	1.525	1.609	1.244	1.495	833	546	1720	1565
7	2.027	2.079	1.746	1.973	1.510	1.610	1.366	1.315	1456	617	1525	1675
8	2.058	2.075	1.785	2.028	1.540	1.631	1.345	1.338	749	601	1590	1555
9	2.126	2.066	1.779	2.048	1.462	1.659	1.416	1.313	658	637	1630	1570
10	2.138	2.097	1.817	1.971	1.476	1.611	1.286	1.365	855	689	1795	1625
XBAR	2.067	2.075	1.791	2.008	1.477	1.626	1.313	1.369	969.6	621.3	1626	1619
VAR	0.002	0.001	0.001	0.001	0.005	0.001	0.005	0.004	63081.38	1896.46	11621.11	4510
STDEV	0.040	0.027	0.030	0.030	0.072	0.027	0.067	0.067	251.16	43.55	107.80	67.16

SCENARIO #3, HL RESULTS

	Det Ranges Blue		Det Ranges Red		Kill Ranges Blue		Kill Ranges Red		Rnds Fired Blue		Rnds Fired Red	
Run #	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
1	1.613	1.718	1.547	1.702	1.327	1.377	1.322	1.474	1960	1276	855	1620
2	1.641	1.707	1.572	1.652	1.312	1.359	1.287	1.412	1068	1303	1315	1410
3	1.665	1.703	1.586	1.634	1.312	1.363	1.300	1.378	1345	1535	1550	1775
4	1.675	1.676	1.612	1.626	1.193	1.420	1.364	1.275	1833	1636	1475	1285
5	1.614	1.733	1.536	1.690	1.319	1.336	1.202	1.572	1257	1361	1155	1760
6	1.723	1.677	1.579	1.651	1.323	1.376	1.394	1.366	1151	1268	1635	1555
7	1.632	1.786	1.538	1.744	1.399	1.373	1.376	1.617	1134	1018	1150	1960
8	1.644	1.747	1.547	1.688	1.241	1.362	1.253	1.438	1131	1486	1685	1760
9	1.623	1.690	1.543	1.620	1.299	1.398	1.403	1.327	1352	1330	1375	1235
10	1.646	1.753	1.530	1.709	1.286	1.386	1.265	1.687	1245	1202	1460	1580
XBAR	1.648	1.719	1.559	1.672	1.301	1.375	1.317	1.455	1347.6	1341.5	1365.5	1594
VAR	0.001	0.001	0.001	0.002	0.003	0.001	0.004	0.018	93197.38	31205.83	64852.5	53604.44
STDEV	0.033	0.036	0.027	0.041	0.055	0.023	0.067	0.133	305.28	176.65	254.66	231.53

APPENDIX C. RAW DATA FOR SAME SEED JLINK RUNS

SCENARIO #1, SWA JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	4	0	1.08	3.844	2.636	248
55	2	1	1	1	3.816	2.707	260
55	3	3	0	1.14	3.851	2.774	158
55	4	1	0	2.09	3.705	2.804	252
55	5	2	0	1.13	3.853	2.851	159
55	6	1	0	1.3	3.786	2.635	182
55	7	0	0	1.17	3.809	2.711	257
55	8	2	0	0.88	3.822	2.645	196
55	9	1	0	0.92	3.837	2.604	224
55	10	4	0	1.17	3.956	2.700	230
	XBAR	1.9	0.1	1.188	3.828	2.707	216.6
	VAR	1.88	0.1	0.116	0.004	0.007	1595.82
	STDEV	1.37	0.32	0.341	0.063	0.081	39.95

SCENARIO #1, HL JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	3	3	1.69	3.544	2.983	328
55	2	1	1	1.21	3.531	2.757	377
55	3	2	3	1.32	3.583	2.776	248
55	4	2	2	1.56	3.624	2.983	219
55	5	0	2	1.43	3.787	3.120	306
55	6	2	2	1.1	3.633	2.763	466
55	7	1	4	1.46	3.438	2.805	307
55	8	2	4	1.91	3.583	2.811	302
55	9	1	1	1.15	3.689	2.617	212
55	10	2	3	1.92	3.691	2.811	277
	XBAR	1.6	2.5	1.475	3.610	2.843	304.2
	VAR	0.71	1.17	0.087	0.010	0.021	5746.62
	STDEV	0.84	1.08	0.295	0.098	0.145	75.81

SCENARIO #2, SWA JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	3	0	1.4	3.364	2.635	147
55	2	0	0	1.17	3.369	2.859	106
55	3	0	0	1.19	3.360	2.441	176
55	4	2	1	1.2	3.514	2.587	158
55	5	2	0	1.35	3.428	2.550	204
55	6	2	0	1.26	3.451	3.480	121
55	7	0	0	1.32	3.223	2.500	258
55	8	1	1	1.17	3.283	2.831	243
55	9	1	0	0.96	3.324	2.539	256
55	10	0	1	1.31	3.339	2.467	319
	XBAR	1.1	0.3	1.233	3.365	2.689	198.8
	VAR	1.21	0.23	0.016	0.007	0.097	4748.62
	STDEV	1.10	0.48	0.125	0.084	0.312	68.91

SCENARIO #2, HL JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	0	2	2.4	2.398	2.745	353
55	2	2	1	1.36	2.254	2.501	527
55	3	1	1	1.5	2.189	2.619	362
55	4	2	2	1.63	2.469	2.692	319
55	5	2	0	1.31	2.264	2.687	426
55	6	2	3	1.77	2.435	2.792	450
55	7	2	4	2.63	2.486	2.787	461
55	8	0	1	1.54	2.518	2.712	336
55	9	2	2	1.59	2.284	2.708	531
55	10	3	2	1.79	2.415	2.498	549
	XBAR	1.6	1.8	1.752	2.371	2.674	431.4
	VAR	0.93	1.29	0.188	0.013	0.011	7426.49
	STDEV	0.97	1.14	0.433	0.114	0.105	86.18

SCENARIO #3, SWA JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	0	0	0.94	2.036	1.526	2396
55	2	0	0	1.18	2.030	1.423	2268
55	3	0	0	0.87	2.059	1.508	2126
55	4	0	0	0.78	2.053	1.511	2228
55	5	0	3	1.03	2.057	1.413	2212
55	6	1	0	1.09	2.060	1.441	2285
55	7	0	0	0.95	2.055	1.482	2340
55	8	0	0	0.95	2.088	1.564	2321
55	9	0	0	0.95	2.022	1.520	2215
55	10	0	0	1	2.046	1.488	2215
	XBAR	0.1	0.3	0.974	2.051	1.488	2260.6
	VAR	0.1	0.9	0.012	0.000	0.002	6070.71
	STDEV	0.32	0.95	0.111	0.019	0.049	77.91

SCENARIO #3, HL JLINK RESULTS

Seed #	Run #	FASCAM Kills	Chem Kills	LER	Detection Ranges	Kill Ranges	Rounds Fired
55	1	1	33	2.22	1.713	1.443	2896
55	2	1	36	2.29	1.726	1.481	3137
55	3	2	42	2.8	1.735	1.414	3455
55	4	0	48	2.81	1.724	1.420	3066
55	5	0	33	1.52	1.738	1.548	2592
55	6	0	24	1.58	1.799	1.493	2835
55	7	0	36	1.93	1.696	1.377	2872
55	8	2	30	2.19	1.686	1.322	3085
55	9	0	33	1.95	1.692	1.402	2839
55	10	0	21	1.87	1.735	1.406	2798
	XBAR	0.6	33.6	2.116	1.724	1.431	2957.5
	VAR	0.71	61.6	0.196	0.001	0.004	56325.17
	STDEV	0.84	7.85	0.442	0.032	0.064	237.33

APPENDEX D. POWER DATA

Scenario #1, SWA				
	Δ	s_p	ϕ	Power
FASCAM	1	0.070	22.54	1.00
Chemical Kills	2	0.601	5.26	1.00
LER	.3	0.271	1.75	.72
Detection Range	.3	0.070	6.76	1.00
Kill Range	.2	0.136	2.32	.88
Rounds Fired	40	42.262	1.50	.54

Scenario #1, HL				
	Δ	s_p	ϕ	Power
FASCAM	1	1.362	1.16	.31
Chemical Kills	2	1.502	2.11	.81
LER	.3	0.320	1.48	.54
Detection Range	.3	0.127	3.73	1.00
Kill Range	.2	0.124	2.56	.93
Rounds Fired	130	188.458	1.09	.29

Scenario #2, SWA				
	Δ	s_p	ϕ	Power
FASCAM	1	1.464	1.08	.28
Chemical Kills	2	0.5	6.33	1.00
LER	.3	0.219	2.17	.83
Detection Range	.3	0.091	5.19	1.00
Kill Range	.2	0.200	1.58	.56
Rounds Fired	40	63.909	0.99	.25

Scenario #2, HL				
	Δ	s_p	ϕ	Power
FASCAM	1	1.174	1.35	.40
Chemical Kills	2	1.354	2.34	.88
LER	.3	0.285	1.66	.62
Detection Range	.3	0.0681	6.96	1.00
Kill Range	.2	0.120	2.63	.94
Rounds Fired	120	144.611	1.31	.40

Scenario #3, SWA				
	Δ	s_p	ϕ	Power
FASCAM	1	1.213	1.30	.40
Chemical Kills	20	2.419	13.07	1.00
LER	.3	0.364	1.30	.40
Detection Range	.2	0.0228	13.90	1.00
Kill Range	.05	0.043	1.84	.69
Rounds Fired	520	171.509	4.79	1.00

Scenario #3, HL				
	Δ	s_p	ϕ	Power
FASCAM	1	0.830	1.91	.72
Chemical Kills	20	6.293	5.03	1.00
LER	.3	0.849	0.56	<.20
Detection Range	.2	0.033	9.60	1.00
Kill Range	.05	0.069	1.14	.31
Rounds Fired	540	268.218	3.18	.986

APPENDIX E. ANALYSIS OF VARIANCE (ANOVA) RESULTS

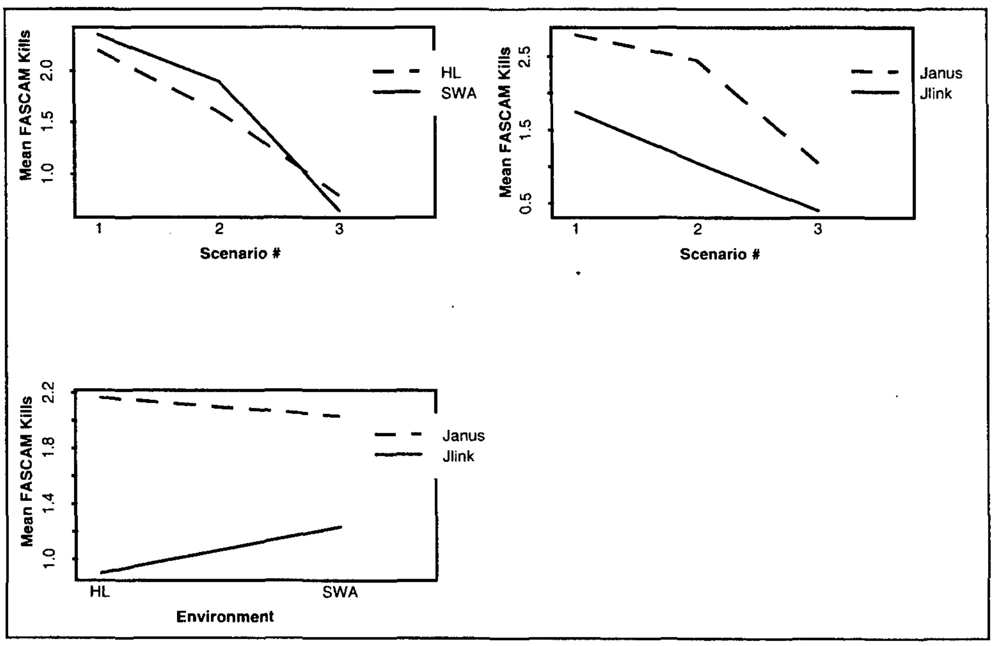
ANOVA FOR FASCAM KILLS

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	49.7167	24.85833	15.62689	0.0000011
Env	1	0.3000	0.30000	0.18859	0.6649580
Mode	1	32.0333	32.03333	20.13737	0.0000181
Scen:Env	2	1.0500	0.52500	0.33003	0.7196211
Scen:Mode	2	2.8167	1.40833	0.88533	0.4155499
Env:Mode	1	1.6333	1.63333	1.02678	0.3131820
Scen:Env:Mode	2	3.8167	1.90833	1.19965	0.3052820
Residuals	108	171.8000	1.59074		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



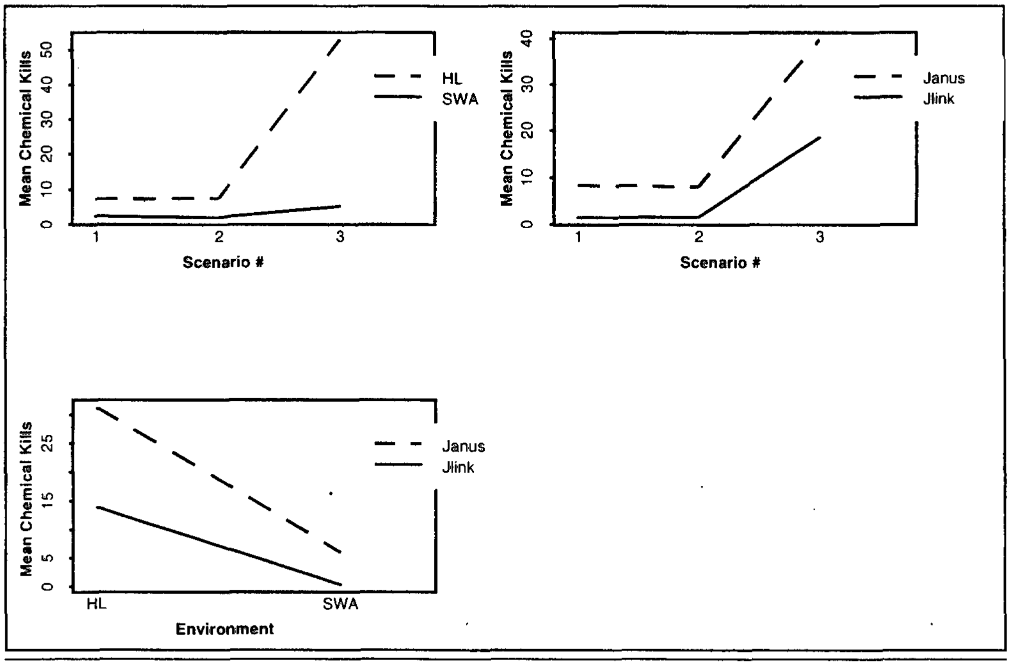
ANOVA FOR CHEMICAL KILLS

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	15811.47	7905.73	945.850	0.000000e+000
Env	1	11427.01	11427.01	1367.140	0.000000e+000
Mode	1	4002.07	4002.07	478.813	0.000000e+000
Scen:Env	2	12043.47	6021.73	720.447	0.000000e+000
Scen:Mode	2	1383.20	691.60	82.744	0.000000e+000
Env:Mode	1	1026.68	1026.68	122.833	0.000000e+000
Scen:Env:Mode	2	540.00	270.00	32.303	1.008882e-011
Residuals	108	902.70	8.36		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



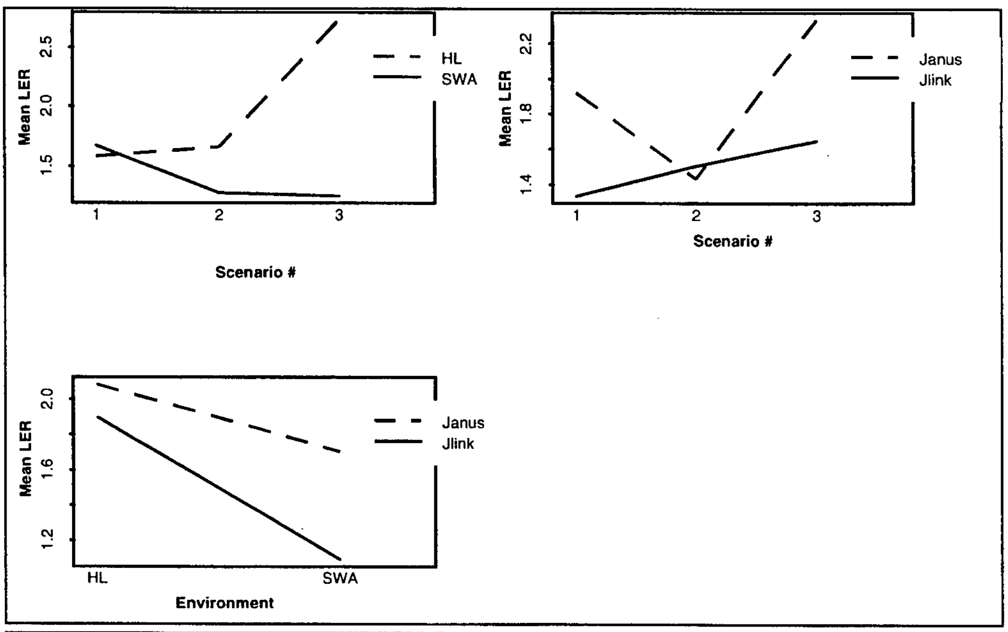
ANOVA FOR LERs

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	5.75032	2.87516	14.90381	0.00000192
Env	1	10.63265	10.63265	55.11590	0.00000000
Mode	1	4.81601	4.81601	24.96450	0.00000226
Scen:Env	2	13.11248	6.55624	33.98523	0.00000000
Scen:Mode	2	3.39263	1.69632	8.79310	0.00028975
Env:Mode	1	1.37388	1.37388	7.12171	0.00878978
Scen:Env:Mode	2	1.30240	0.65120	3.37560	0.03784347
Residuals	108	20.83476	0.19291		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



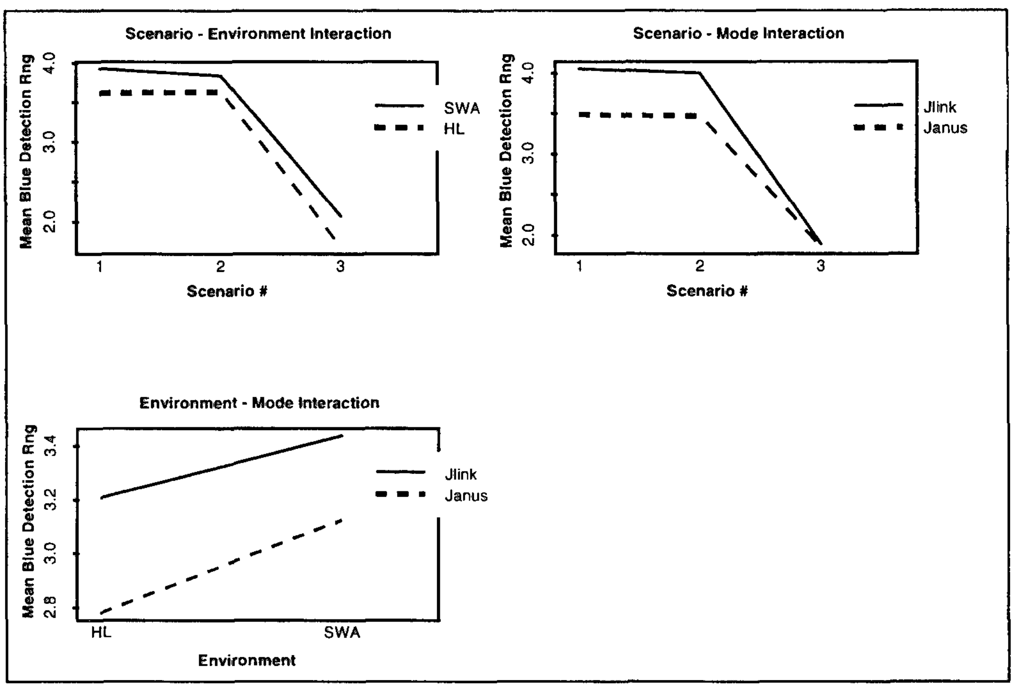
ANOVA for Detection Range Blue

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	95.34164	47.67082	6050.279	0.0000000
Env	1	2.51797	2.51797	319.576	0.0000000
Mode	1	4.11438	4.11438	522.188	0.0000000
Scen:Env	2	0.19275	0.09638	12.232	0.0000163
Scen:Mode	2	1.64627	0.82313	104.470	0.0000000
Env:Mode	1	0.09369	0.09369	11.892	0.0008050
Scen:Env:Mode	2	0.00861	0.00431	0.547	0.5805110
Residuals	108	0.85094	0.00788		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



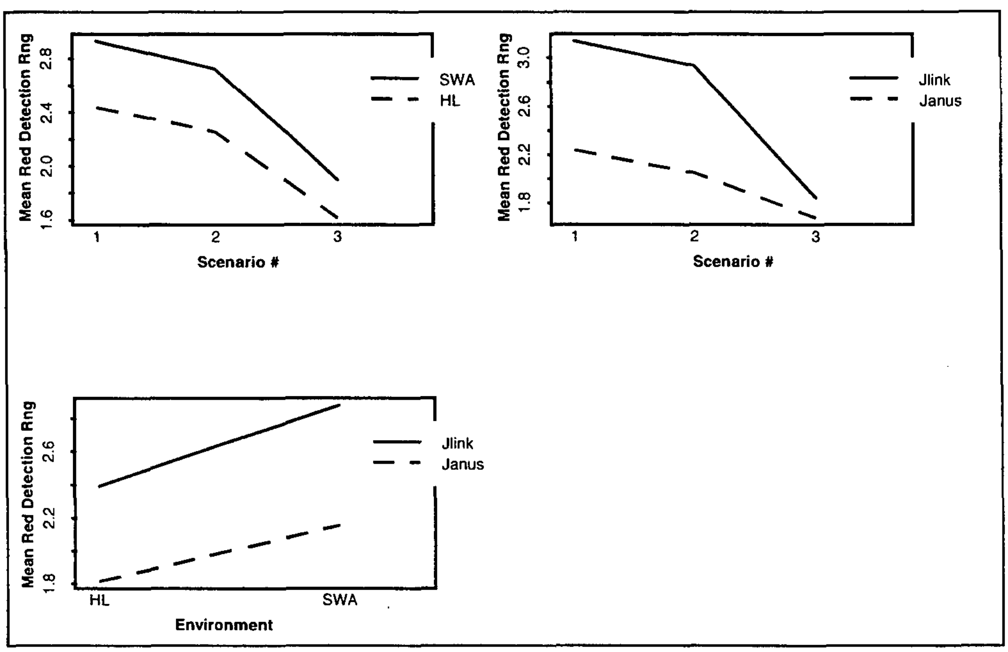
ANOVA for Detection Range Red

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	19.16607	9.58304	588.7363	0.00000000
Env	1	5.15815	5.15815	316.8920	0.00000000
Mode	1	12.66121	12.66121	777.8444	0.00000000
Scen:Env	2	0.25595	0.12797	7.8622	0.00064909
Scen:Mode	2	3.52387	1.76194	108.2451	0.00000000
Env:Mode	1	0.15869	0.15869	9.7494	0.00230238
Scen:Env:Mode	2	0.08810	0.04405	2.7063	0.07131454
Residuals	108	1.75795	0.01628		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



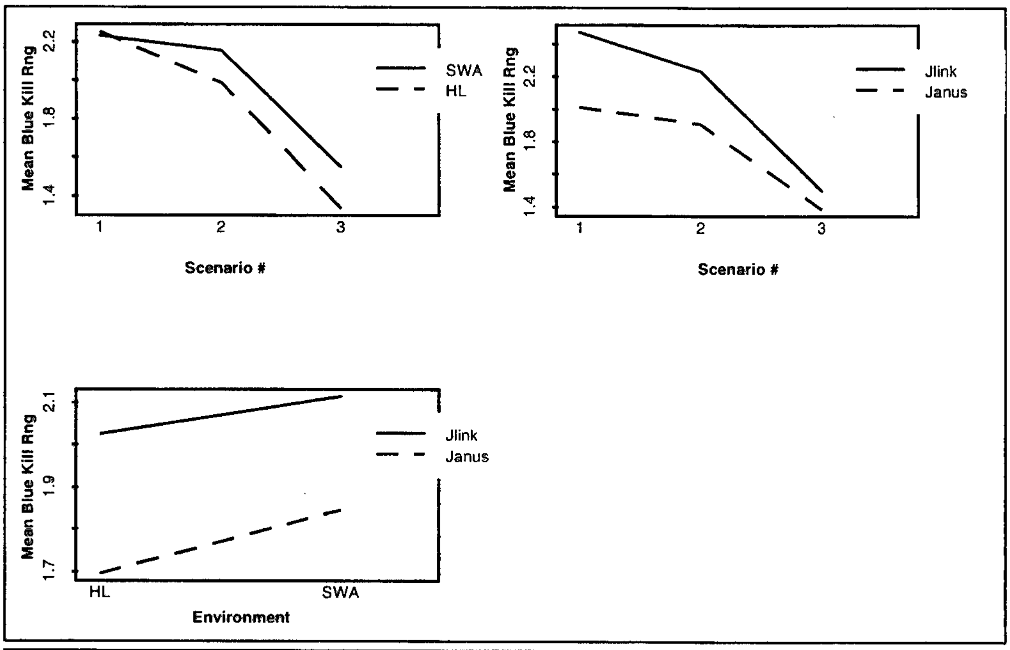
ANOVA for Kill Range Blue

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	14.17509	7.087543	111.0971	0.0000000
Env	1	0.43093	0.430931	6.7548	0.0106554
Mode	1	2.68719	2.687186	42.1216	0.0000000
Scen:Env	2	0.31075	0.155376	2.4355	0.0923476
Scen:Mode	2	0.62021	0.310106	4.8609	0.0095194
Env:Mode	1	0.02739	0.027389	0.4293	0.5137113
Scen:Env:Mode	2	0.18702	0.093509	1.4658	0.2354604
Residuals	108	6.88996	0.063796		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



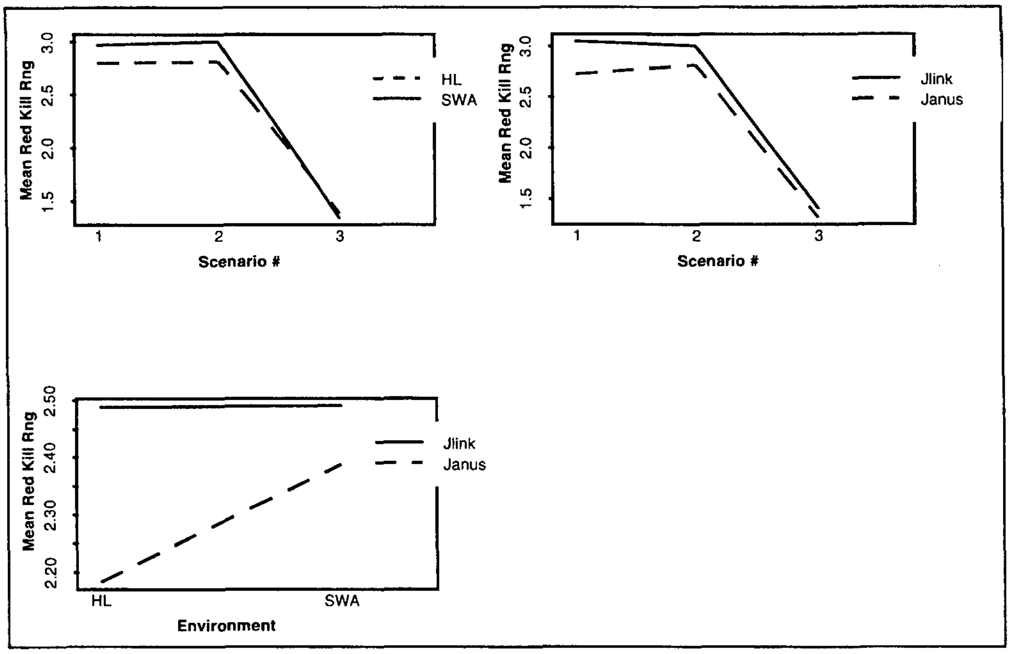
ANOVA for Kill Range Red

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	62.94847	31.47423	1426.979	0.00000000
Env	1	0.32467	0.32467	14.720	0.00021033
Mode	1	1.24480	1.24480	56.437	0.00000000
Scen:Env	2	0.33175	0.16587	7.520	0.00087544
Scen:Mode	2	0.25323	0.12661	5.740	0.00427329
Env:Mode	1	0.30617	0.30617	13.881	0.00031162
Scen:Env:Mode	2	0.13178	0.06589	2.987	0.05460434
Residuals	108	2.38211	0.02206		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



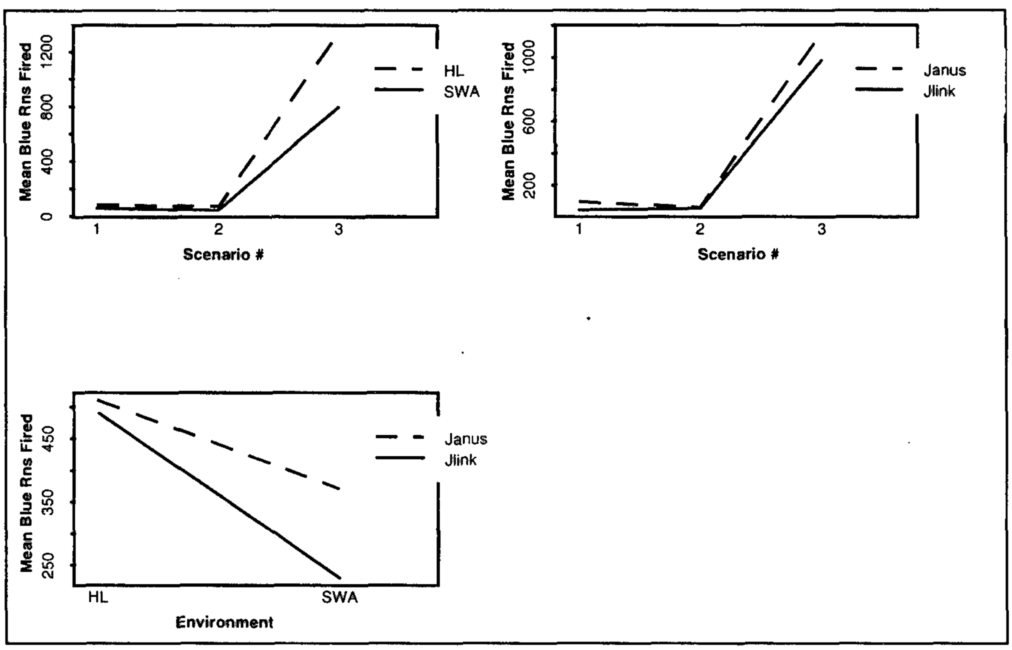
ANOVA for Rounds Fired Blue

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	26900478	13450239	834.6258	0.00000000
Env	1	1207813	1207813	74.9482	0.00000000
Mode	1	192240	192240	11.9290	0.00079057
Scen:Env	2	1821263	910631	56.5073	0.00000000
Scen:Mode	2	151142	75571	4.6894	0.01114398
Env:Mode	1	110231	110231	6.8402	0.01018746
Scen:Env:Mode	2	183874	91937	5.7049	0.00441275
Residuals	108	1740452	16115		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.



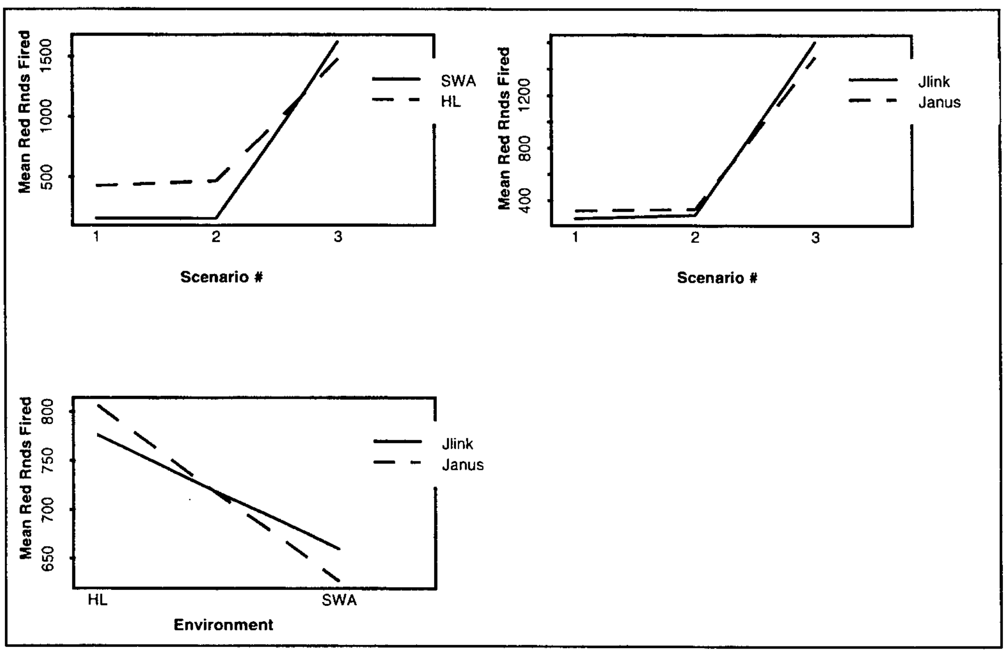
ANOVA for Rounds Fired Red

Analysis of Variance Table
Response: MOE

Terms added sequentially (first to last)

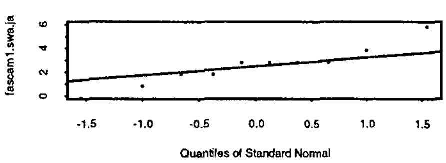
	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Scen	2	41699636	20849818	943.9545	0.0000000
Env	1	660677	660677	29.9115	0.0000003
Mode	1	65	65	0.0029	0.9569931
Scen:Env	2	1278612	639306	28.9439	0.0000000
Scen:Mode	2	180512	90256	4.0863	0.0194671
Env:Mode	1	30401	30401	1.3764	0.2433019
Scen:Env:Mode	2	367668	183834	8.3229	0.0004348
Residuals	108	2385475	22088		

Interaction plots for scenario:environment, scenario:mode, and environment:mode.

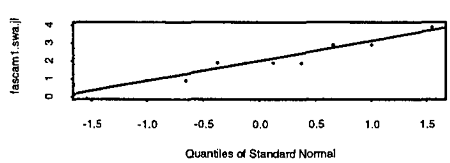


APPENDIX F. NORMAL QUANTILE-QUANTILE PLOTS

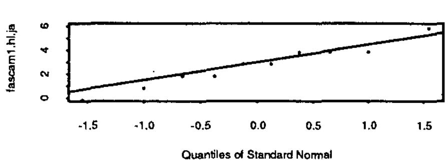
FASCAM,Scen #1,SWA,Janus



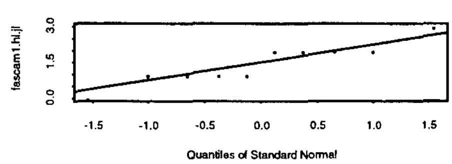
FASCAM,Scen #1,SWA,JLINK



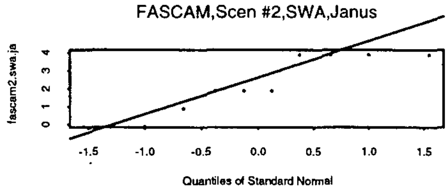
FASCAM,Scen #1,HL,Janus



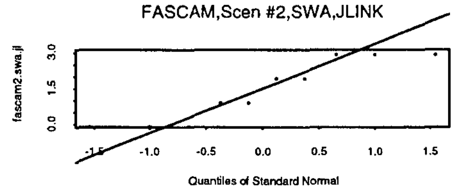
FASCAM,Scen #1,HL,JLINK



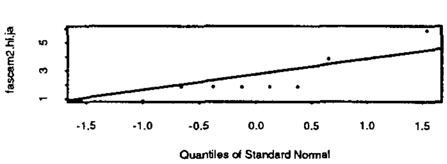
FASCAM,Scen #2,SWA,Janus



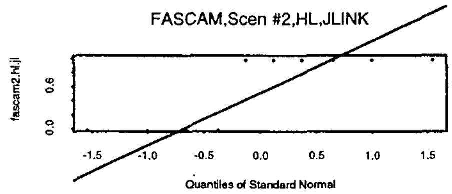
FASCAM,Scen #2,SWA,JLINK



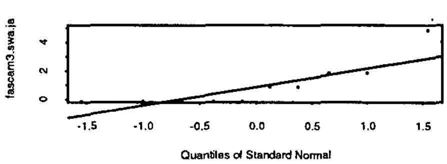
FASCAM,Scen #2,HL,Janus



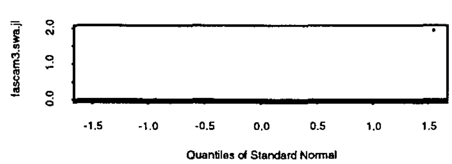
FASCAM,Scen #2,HL,JLINK



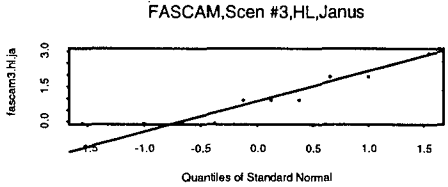
FASCAM,Scen #3,SWA,Janus



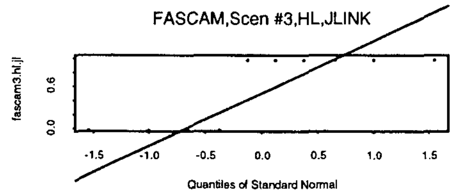
FASCAM,Scen #3,SWA,JLINK

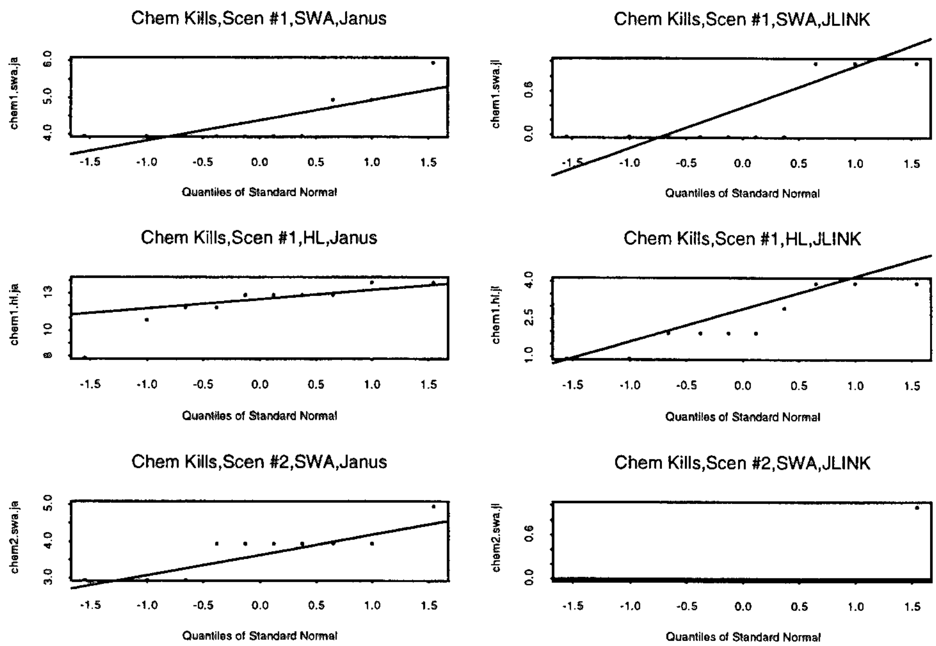


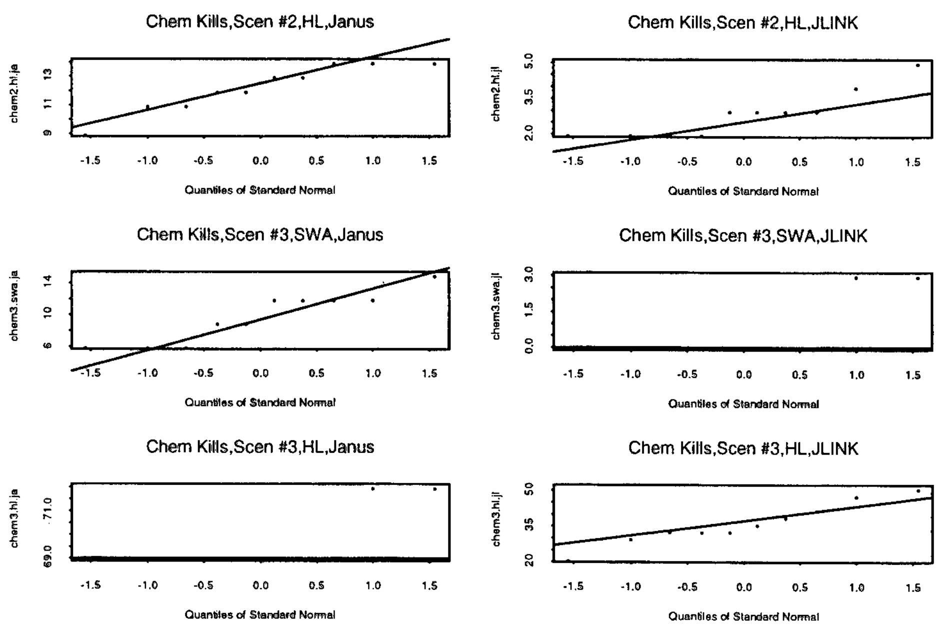
FASCAM,Scen #3,HL,Janus

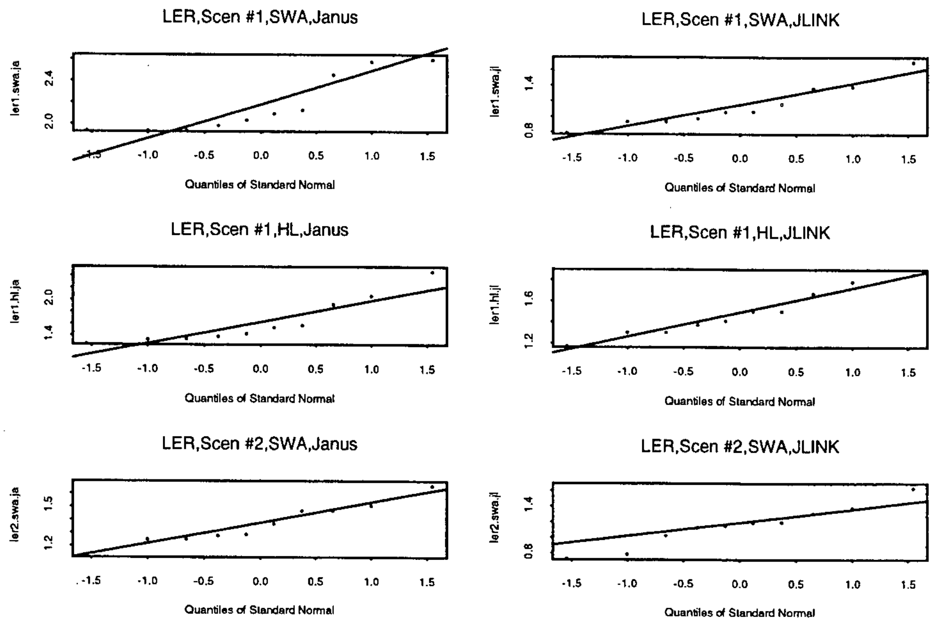


FASCAM,Scen #3,HL,JLINK




Chem Kills,Scen #1,SWA,Janus
chem1.swa.ja
Quantiles of Standard Normal
Chem Kills,Scen #1,SWA,JLINK
chem1.swa.jl
Quantiles of Standard Normal
Chem Kills,Scen #1,HL,Janus
chem1.hl.ja
Quantiles of Standard Normal
Chem Kills,Scen #1,HL,JLINK
chem1.hl.jl
Quantiles of Standard Normal
Chem Kills,Scen #2,SWA,Janus
chem2.swa.ja
Quantiles of Standard Normal
Chem Kills,Scen #2,SWA,JLINK
chem2.swa.jl
Quantiles of Standard Normal


Chem Kills,Scen #2,HL,Janus
chem2.hl.ja
Quantiles of Standard Normal
Chem Kills,Scen #2,HL,JLINK
chem2.hl.jl
Quantiles of Standard Normal
Chem Kills,Scen #3,SWA,Janus
chem3.swa.ja
Quantiles of Standard Normal
Chem Kills,Scen #3,SWA,JLINK
chem3.swa.jl
Quantiles of Standard Normal
Chem Kills,Scen #3,HL,Janus
chem3.hl.ja
Quantiles of Standard Normal
Chem Kills,Scen #3,HL,JLINK
chem3.hl.jl
Quantiles of Standard Normal


LER,Scen #1,SWA,Janus
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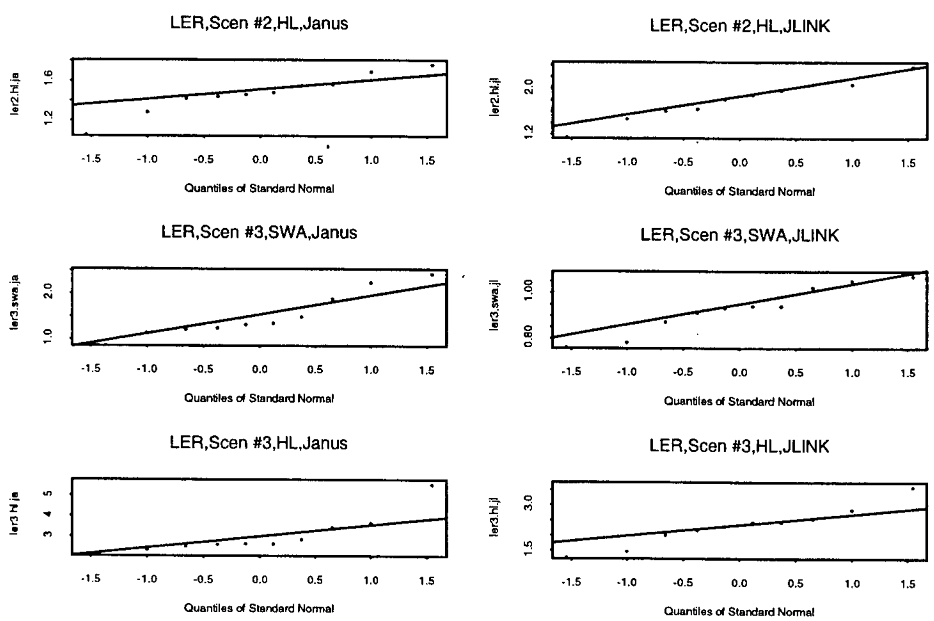
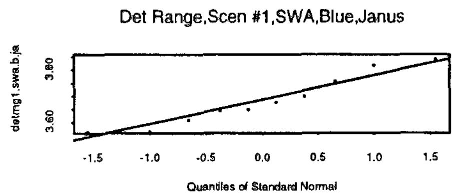
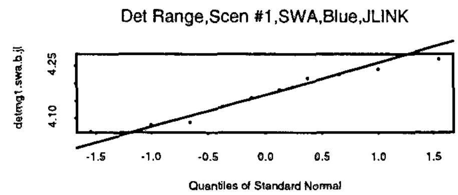
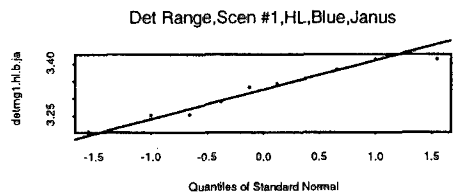
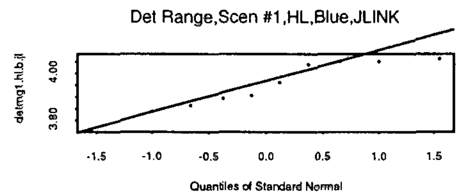
LER,Scen #1,SWA,JLINK
ler1.swa.jl
LER,Scen #1,HL,Janus
ler1.hl.ja
LER,Scen #1,HL,JLINK
ler1.hl.jl
LER,Scen #2,SWA,Janus
ler2.swa.ja
LER,Scen #2,SWA,JLINK
ler2.swa.jl
Quantiles of Standard Normal

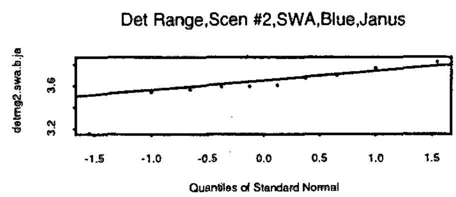

LER,Scen #2,HL,Janus
ler2.hl.ja
LER,Scen #2,HL,JLINK
ler2.hl.jl
LER,Scen #3,SWA,Janus
ler3.swa.ja
LER,Scen #3,SWA,JLINK
ler3.swa.jl
LER,Scen #3,HL,Janus
ler3.hl.ja
LER,Scen #3,HL,JLINK
ler3.hl.jl
Quantiles of Standard Normal

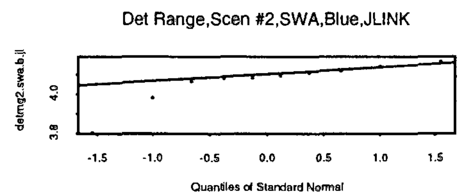

Det Range,Scen #1,SWA,Blue,Janus
detrng1.swa.b.ja
Quantiles of Standard Normal

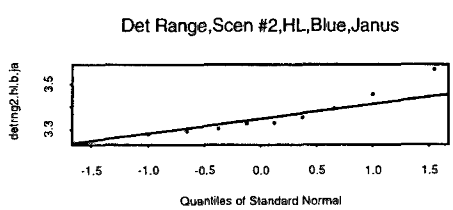

Det Range,Scen #1,SWA,Blue,JLINK
detrng1.swa.b.jl
Quantiles of Standard Normal

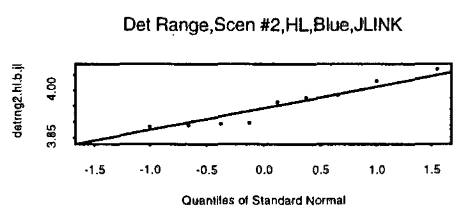

Det Range,Scen #1,HL,Blue,Janus
detrng1.hl.b.ja
Quantiles of Standard Normal

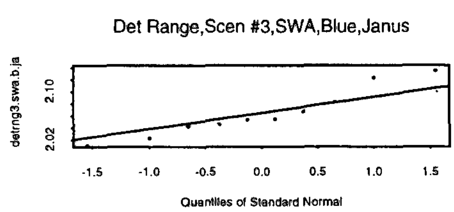

Det Range,Scen #1,HL,Blue,JLINK
detrng1.hl.b.jl
Quantiles of Standard Normal

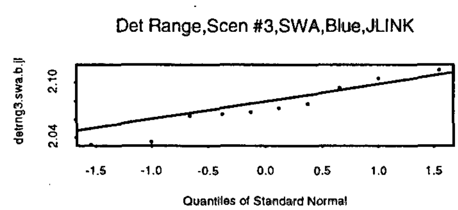

Det Range,Scen #2,SWA,Blue,Janus
detrng2.swa.b.ja
Quantiles of Standard Normal

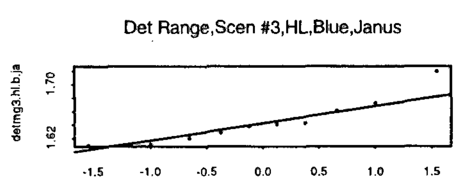

Det Range,Scen #2,SWA,Blue,JLINK
detrng2.swa.b.jl
Quantiles of Standard Normal

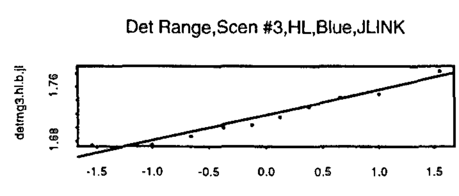

Det Range,Scen #2,HL,Blue,Janus
detrng2.hl.b.ja
Quantiles of Standard Normal


Det Range,Scen #2,HL,Blue,JLINK
detrng2.hl.b.jl
Quantiles of Standard Normal

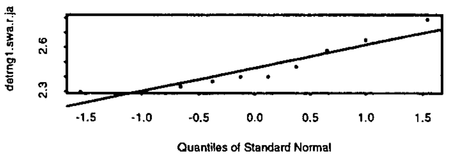

Det Range,Scen #3,SWA,Blue,Janus
detrng3.swa.b.ja
Quantiles of Standard Normal


Det Range,Scen #3,SWA,Blue,JLINK
detrng3.swa.b.jl
Quantiles of Standard Normal

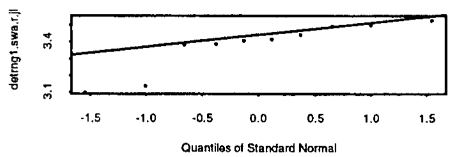

Det Range,Scen #3,HL,Blue,Janus
detrng3.hl.b.ja
Quantiles of Standard Normal


Det Range,Scen #3,HL,Blue,JLINK
detrng3.hl.b.jl
Quantiles of Standard Normal

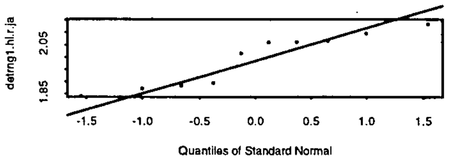
Det Range,Scen #1,SWA,Red,Janus



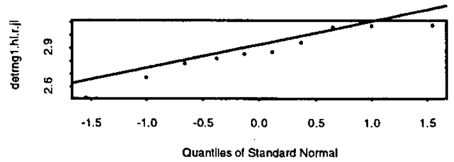
Det Range,Scen #1,SWA,Red,JLINK



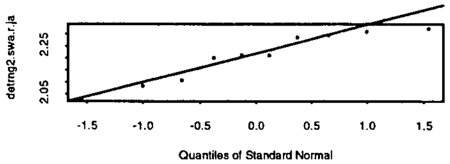
Det Range,Scen #1,HL,Red,Janus



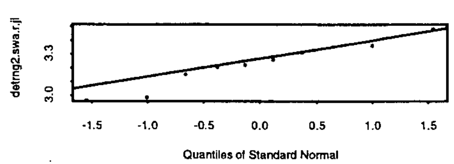
Det Range,Scen #1,HL,Red,JLINK



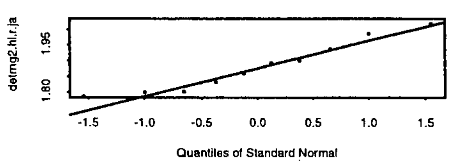
Det Range,Scen #2,SWA,Red,Janus



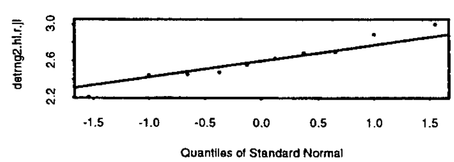
Det Range,Scen #2,SWA,Red,JLINK



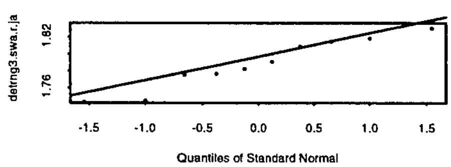
Det Range,Scen #2,HL,Red,Janus



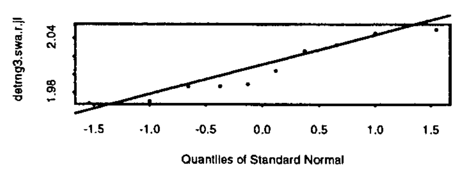
Det Range,Scen #2,HL,Red,JLINK



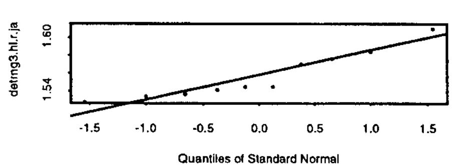
Det Range,Scen #3,SWA,Red,Janus



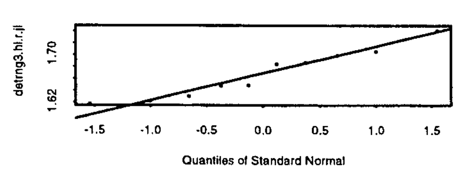
Det Range,Scen #3,SWA,Red,JLINK



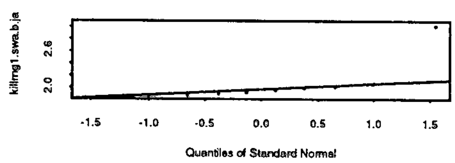
Det Range,Scen #3,HL,Red,Janus



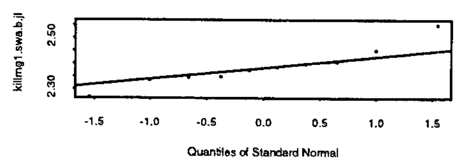
Det Range,Scen #3,HL,Red,JLINK



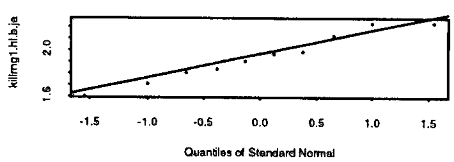
Kill Range,Scen #1,SWA,Blue,Janus



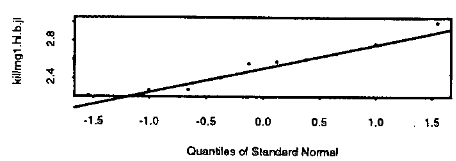
Kill Range,Scen #1,SWA,Blue,JLINK



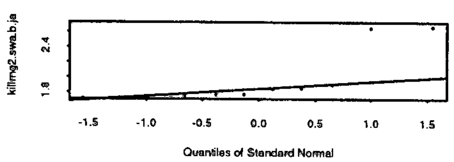
Kill Range,Scen #1,HL,Blue,Janus



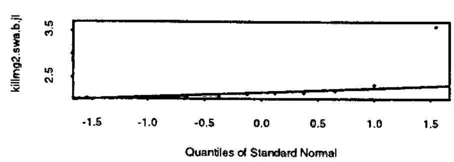
Kill Range,Scen #1,HL,Blue,JLINK



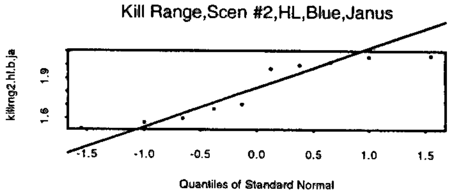
Kill Range,Scen #2,SWA,Blue,Janus



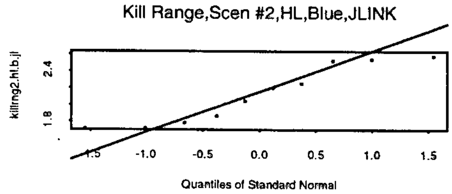
Kill Range,Scen #2,SWA,Blue,JLINK



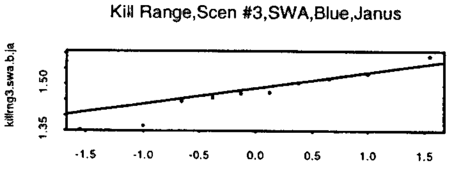
Kill Range,Scen #2,HL,Blue,Janus



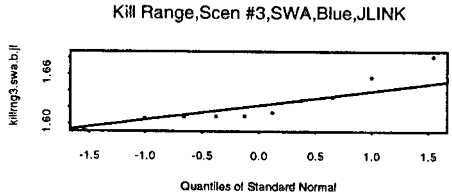
Kill Range,Scen #2,HL,Blue,JLINK



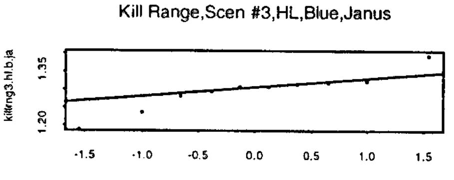
Kill Range,Scen #3,SWA,Blue,Janus



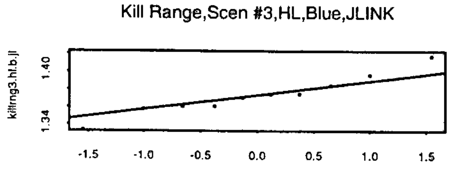
Kill Range,Scen #3,SWA,Blue,JLINK



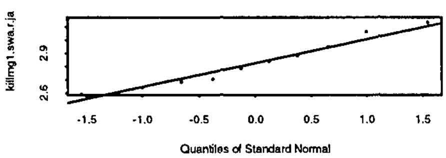
Kill Range,Scen #3,HL,Blue,Janus



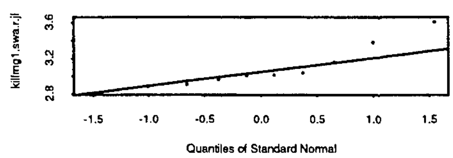
Kill Range,Scen #3,HL,Blue,JLINK



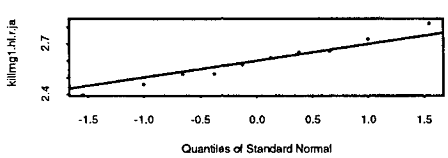
Kill Range,Scen #1,SWA,Red,Janus



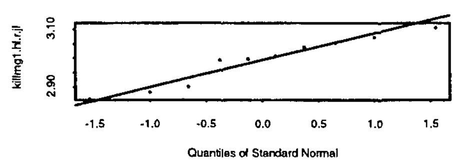
Kill Range,Scen #1,SWA,Red,JLINK



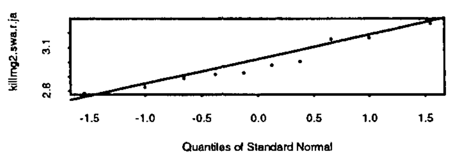
Kill Range,Scen #1,HL,Red,Janus



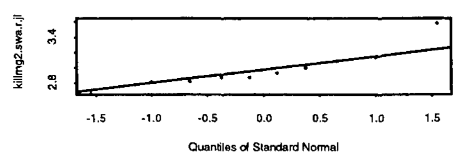
Kill Range,Scen #1,HL,Red,JLINK



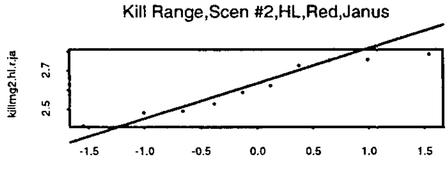
Kill Range,Scen #2,SWA,Red,Janus



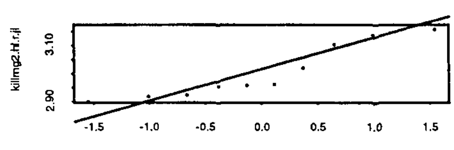
Kill Range,Scen #2,SWA,Red,JLINK



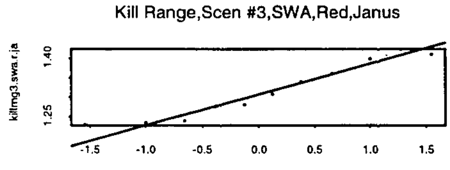
Kill Range,Scen #2,HL,Red,Janus



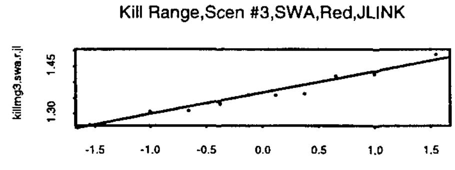
Kill Range,Scen #2,HL,Red,JLINK



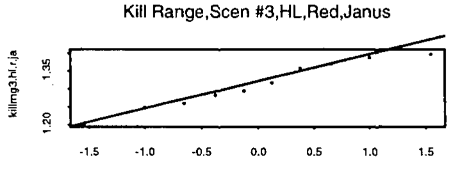
Kill Range,Scen #3,SWA,Red,Janus



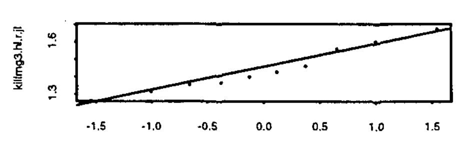
Kill Range,Scen #3,SWA,Red,JLINK



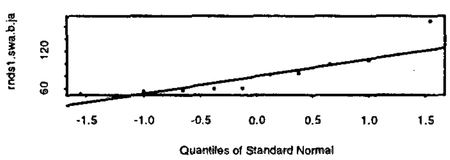
Kill Range,Scen #3,HL,Red,Janus



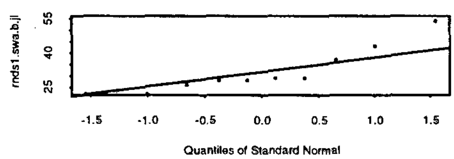
Kill Range,Scen #3,HL,Red,JLINK



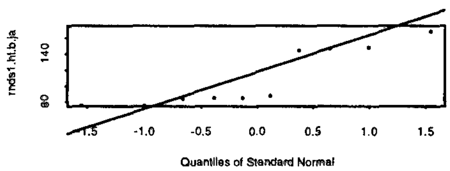
Rnds Fired,Scen #1,SWA,Blue,Janus



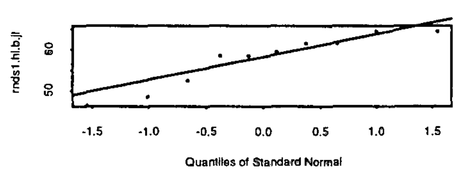
Rnds Fired,Scen #1,SWA,Blue,JLINK



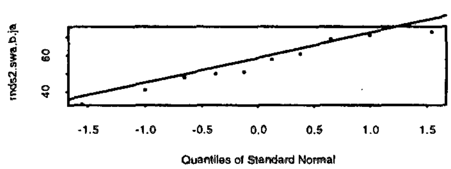
Rnds Fired,Scen #1,HL,Blue,Janus



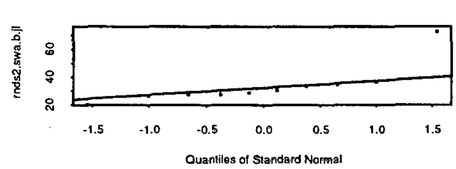
Rnds Fired,Scen #1,HL,Blue,JLINK



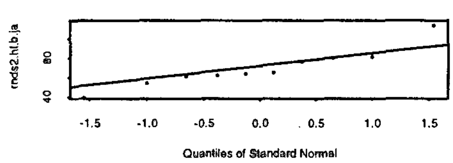
Rnds Fired,Scen #2,SWA,Blue,Janus



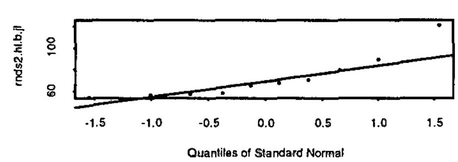
Rnds Fired,Scen #2,SWA,Blue,JLINK



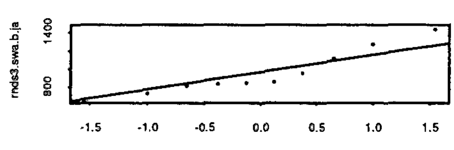
Rnds Fired,Scen #2,HL,Blue,Janus



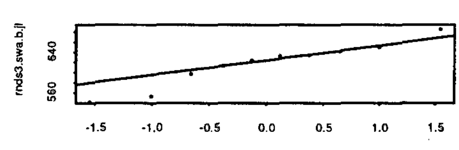
Rnds Fired,Scen #2,HL,Blue,JLINK



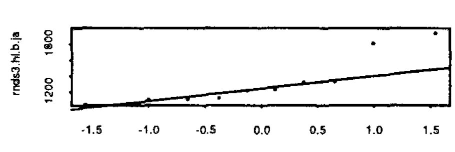
Rnds Fired,Scen #3,SWA,Blue,Janus



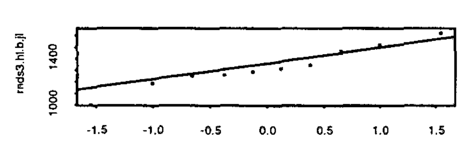
Rnds Fired,Scen #3,SWA,Blue,JLINK



Rnds Fired,Scen #3,HL,Blue,Janus



Rnds Fired,Scen #3,HL,Blue,JLINK



APPENDIX G. KOLMOGOROV-SMIRNOV GOODNESS OF FIT RESULTS

Highlighted portions are those MOPs which produce p-values<0.05 (α=0.05), and thus reject the null hypothesis that the sample comes from a Normal distribution.

Scenario #1, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.60	.75	.04	.03	.44	.73

Scenario #1, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.92	.63	.47	.42	.43	.84

Scenario #2, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.48	.84	.20	.004	.79	.89

Scenario #2, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.14	.08	.91	.44	.74	.99

Scenario #3, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.46	.004	.51	.01	.59	.95

Scenario #3, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.60	.08	.001	.93	.38	.93

Scenario #1, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.98	.93	.57	.25	.10	.84	.94	.44	.63	.24	.93	.89
Scenario #1, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.97	.65	.56	.92	.99	.95	.99	.75	.19	.45	.94	.98
Scenario #2, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.41	.21	.78	.95	.08	.10	.92	.91	.97	.19	.40	.85
Scenario #2, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.78	.58	.96	.96	.46	.85	.82	.43	.80	.58	.97	.81
Scenario #3, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.68	.52	.92	.64	.98	.26	.98	.76	.50	.92	.82	.90
Scenario #3, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
P-Value	.47	.97	.33	.87	.70	.44	.97	.98	.29	.94	.97	.91

APPENDIX H. *F*-TEST FOR COMMON VARIANCE RESULTS

Highlighted portions are those MOPs which produce p-values<0.05 (α=0.05), and thus reject the null hypothesis that the two samples share a common variance.

Scenario #1, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.31		.29		.97	
Scenario #1, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.045		.24		.10	
Scenario #2, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.46		.051		.14	
Scenario #2, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.003		.15		.11	
Scenario #3, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.01		.01		.00	
Scenario #3, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.045		.00		.23	

Scenario #1, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.39		.73		.00		.37		.00		.76	

Scenario #1, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.24		.13		.66		.23		.00		.00	

Scenario #2, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.12		.19		.50		.17		.82		.01	

Scenario #2, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.45		.00		.21		.31		.94		.99	

Scenario #3, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.25		.98		.01		.98		.00		.17	

Scenario #3, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
P-Value	.84		.22		.02		.05		.12		.78	

APPENDIX I. *t*-TEST RESULTS

Highlighted portions are those MOPs which produce p-values<0.0083, ($\alpha_{new} = \alpha_{old} / 6 = 0.0083$) and thus reject the null hypothesis that the two sample means are statistically similar. Also, the $1\text{-}\alpha_{new} = 99.17$ percent confidence interval (CI) is provided to show the extent to which the sample means are similar (dissimilar). All MOPs failing to reject the null hypothesis (p-value>0.0083) produce CIs which include zero.

Scenario #1, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-1.18 , 2.58)				(.66 , 1.38)	
p-value	.28		na		.00	
Scenario #1, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
CI			(7.81 , 11.79)		(-.27 , .58)	
p-value	na		.00		.30	
Scenario #2, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-1.14 , 2.74)				(-.09 , .49)	
p-value	.24		na		.05	
Scenario #2, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
CI					(-.72 , .03)	
p-value	na		na		.014	
Scenario #3, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	na		na		na	
Scenario #3, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
CI					(-.37 , 1.88)	
p-value	na		na		.06	

Scenario #1, SWA

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.60 , -.37)		(-1.13 , -.71)		(-.66 , .02)		(-.54 , .03)		(17.52 , 87.48)		(-129.14 , -41.26)	
P-Value	.00		.00		.02		.02		.00		.00	

Scenario #1, HL

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.74 , -.50)		(-1.08 , -.68)		(-.91 , -.30)		(-.53 , -.25)		(19.14 , 89.26)		(-60.62 , 476.82)	
P-Value	.00		.00		.00		.00		.00		.03	

Scenario #2, SWA

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.65 , -.26)		(-1.21 , -.85)		(-.90 , .22)		(-.28 , .28)		(2.88 , 39.52)		(-104.78 , 61.38)	
P-Value	.00		.00		.09		.99		.003		.45	

Scenario #2, HL

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.70 , -.47)		(-.97 , -.51)		(-.70 , .07)		(-.54 , -.23)		(-28.42 , 24.42)		(-71.46 , 294.46)	
P-Value	.00		.00		.03		.00		.83		.09	

Scenario #3, SWA

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.05 , .04)		(-.26 , -.18)		(-.22 , -.08)		(-.14 , .03)		(109.48 , 587.12)		(-111.99 , 125.99)	
P-Value	.63		.00		.00		.07		.00		.86	

Scenario #3, HL

	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink	Janus	JLink
CI	(-.12 , -.03)		(-.16 , -.07)		(-.13 , -.02)		(-.28 , .001)		(-324.35 , 336.55)		(-550.96 , 93.96)	
P-Value	.00		.00		.001		.009		.96		.05	

APPENDIX J. WILCOXEN TEST RESULTS

Highlighted portions those MOPs which produce p-values<0.0083, ($\alpha_{old} / 6 = 0.0083$) and thus reject the null hypothesis that the two sample means are statistically similar.

Scenario #1, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.29		.000		.000	
Scenario #1, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.04		.000		.47	
Scenario #2, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.26		.000		.05	
Scenario #2, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.001		.000		.02	
Scenario #3, SWA						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.08		.000		.001	
Scenario #3, HL						
	FASCAM		Chem Kills		LER	
Mode	Janus	JLink	Janus	JLink	Janus	JLink
p-value	.49		.000		.04	

Scenario #1, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.000		.000		.0015		.02		.000		.000	
Scenario #1, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.000		.000		.000		.000		.000		.08	
Scenario #2, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.000		.000		.01		.74		.005		.12	
Scenario #2, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.000		.000		.04		.000		.97		.08	
Scenario #3, SWA												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.48		.000		.000		.11		.000		.94	
Scenario #3, HL												
	Det Rng Blue		Det Rng Red		Kill Rng Blue		Kill Rng Red		Rnds Fired Blue		Rnds Fired Red	
Mode	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK	Janus	JLINK
p-value	.000		.000		.0011		.009		.48		.06	

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